High contrast imaging and coronagraphy at ESO

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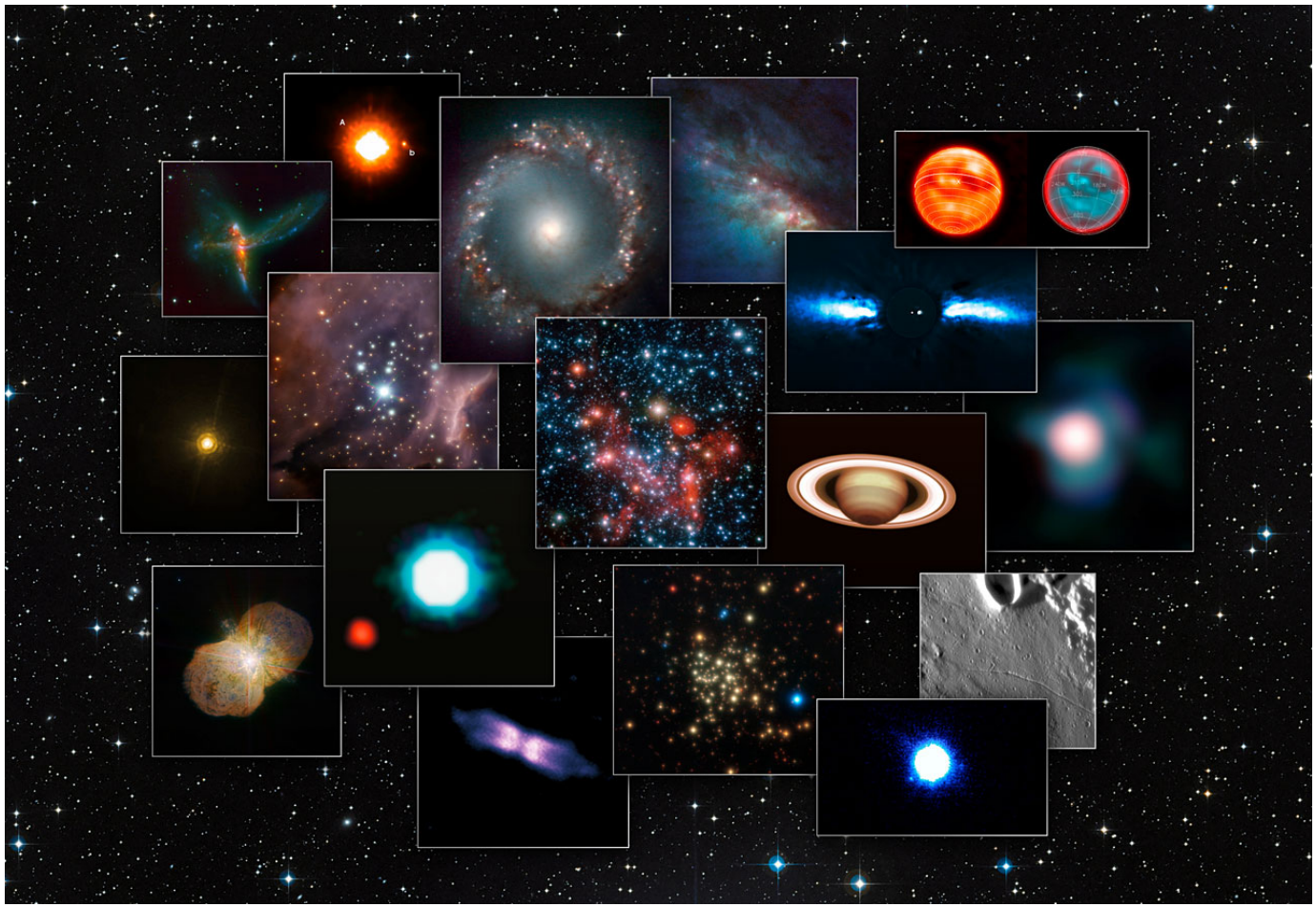
Content

- 10 years of adaptive optics at Paranal
  - NACO before
  - The potential future of NACO
- VISIR+
  - Coronagraphy with VISIR
  - Vector Vortex on VISIR
- SPHERE
  - The beast is coming soon to Paranal!
  - Potential game changer
- Glimpse of the future

10 YEARS of AO at ESO!

- 10 years of adaptive optics at Paranal (NACO):

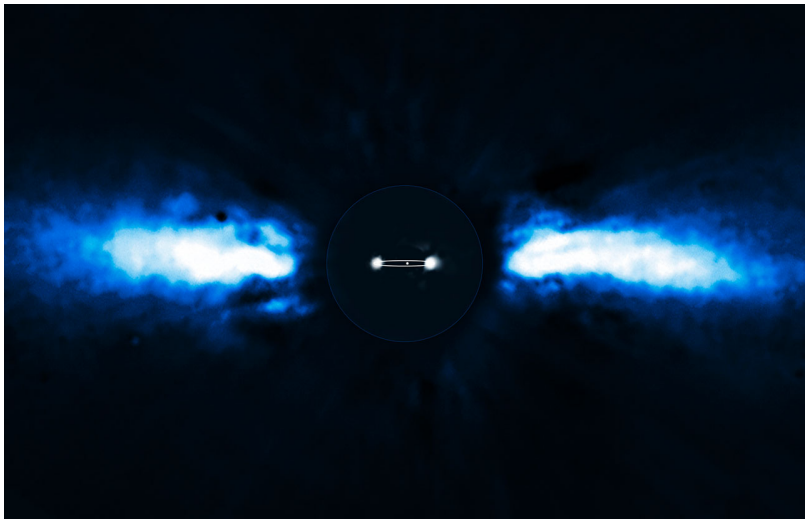


NACO

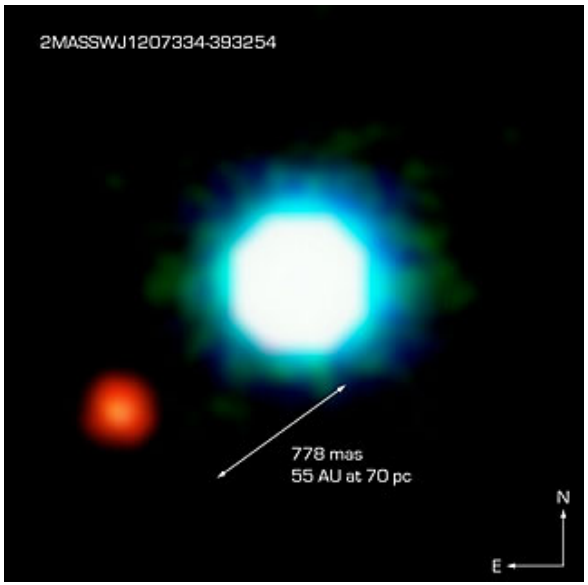
- NAOS-CONICA
  - Unique AO instrument:
    - Flexibility of visible and IR WFS
    - 14x14 DM (480 Hz)
    - Tons of modes:
      - Imaging J-M
      - Coronagraphy: Lyot, FQPM, APP
      - Polarimetry
      - Low-resolution Spectroscopy

Exoplanet science

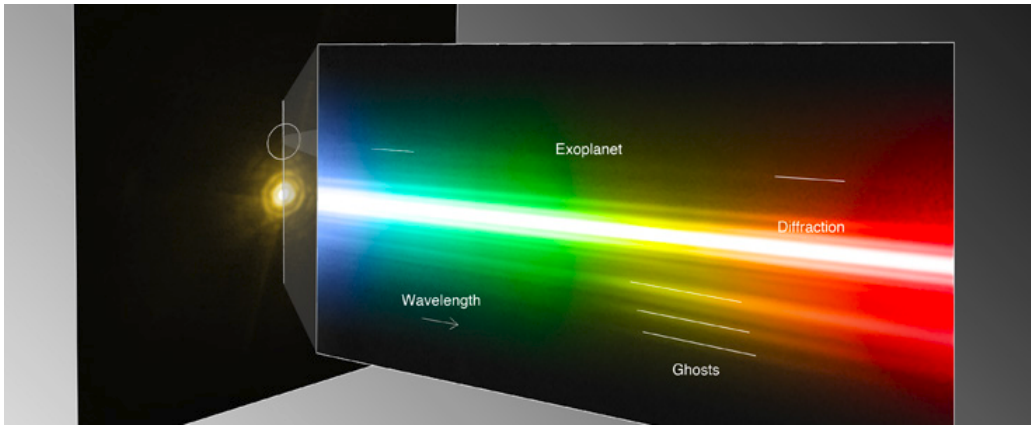
- Exoplanets with NACO:



Lagrange et al 2008, 2009, 2012



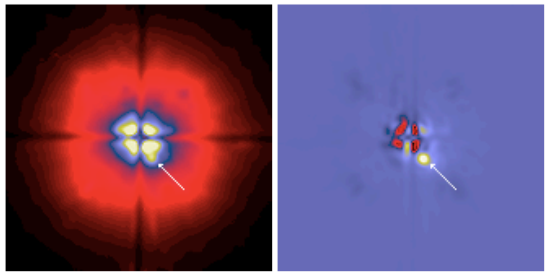
Chauvin et al 2004



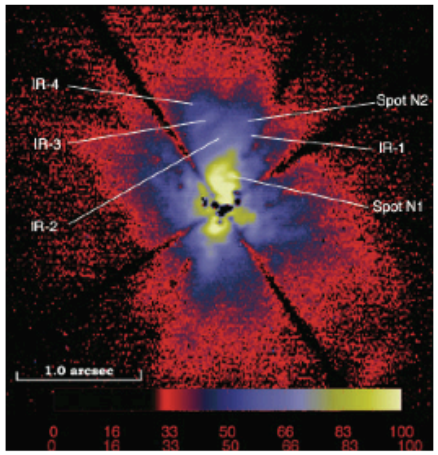
Janson et al 2010

Nexgen coronagraphy in action

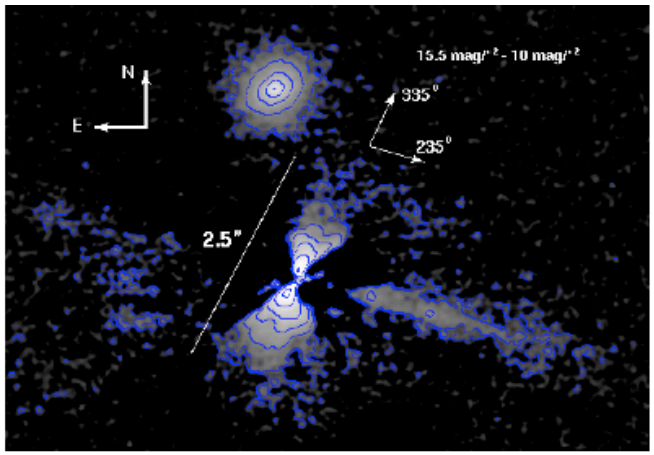
- A few results with the FQPM of NACO



AB Dor C: Boccaletti, Chauvin, Baudoz, Beuzit, et al. 2008



NGS1068: Gratadour, Rouan et al. 2005

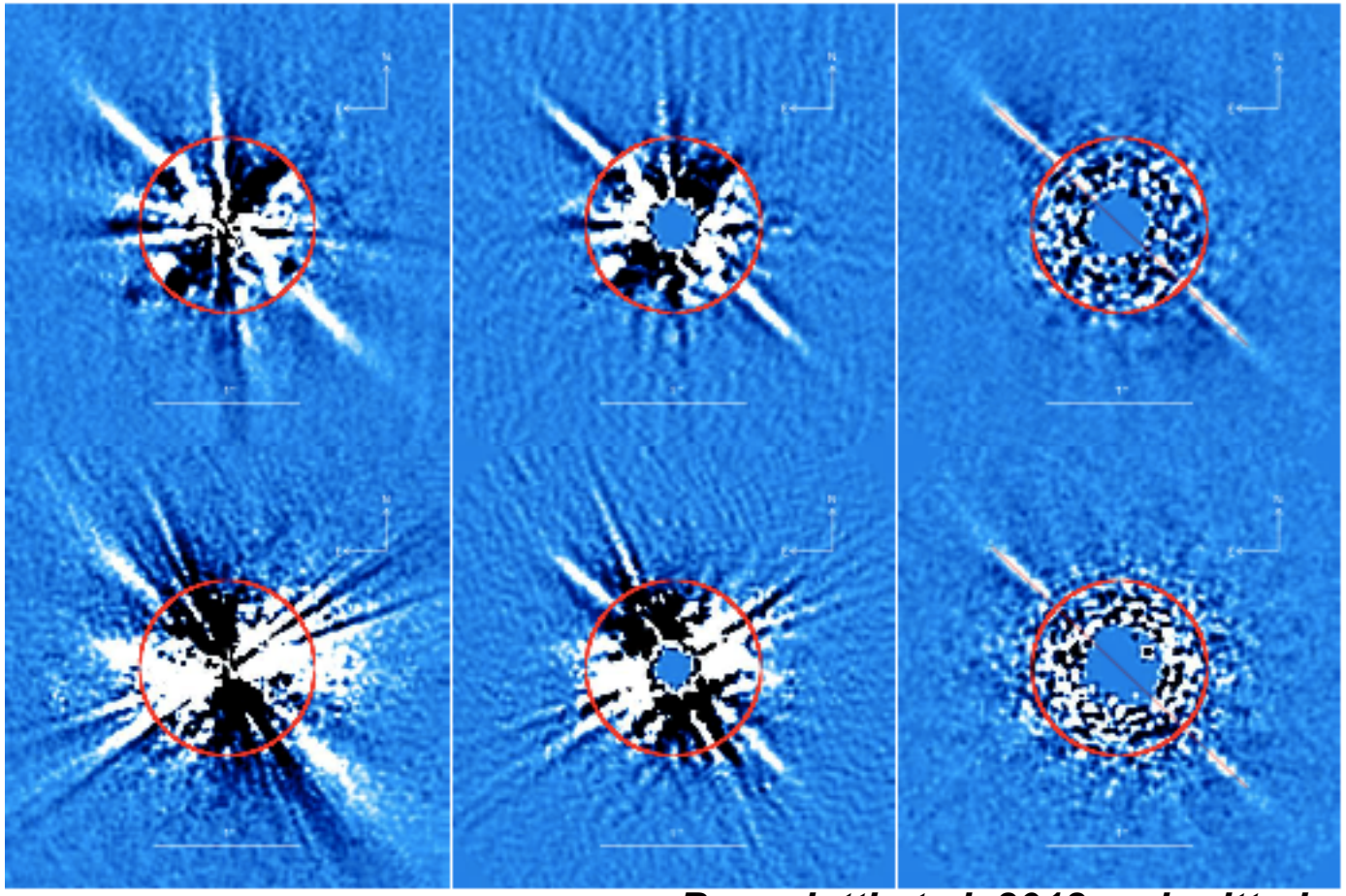


PDS70: Riaud, Mawet, Absil, et al. 2006

The FQPM is the most productive nexgen coronagraph so far!

Recent exciting results

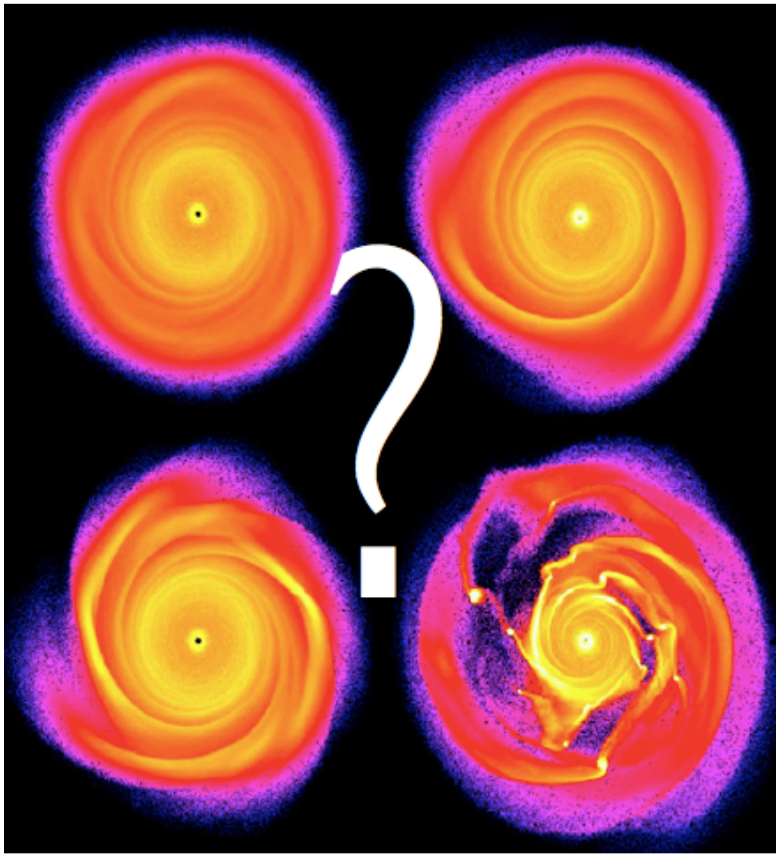
- HD32297 at high resolution using FQPM / ADI



Boccaletti et al. 2012, submitted

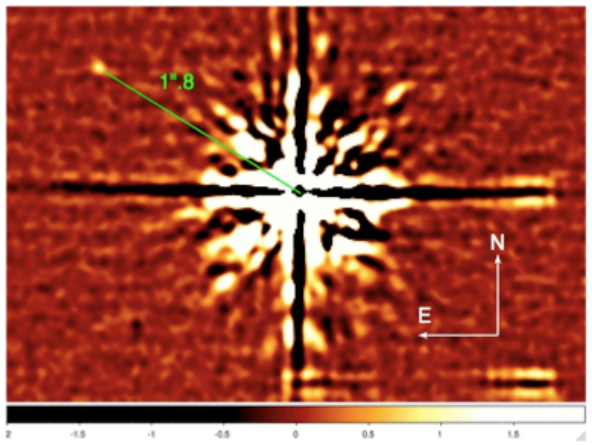
Planet search around IM Lupi

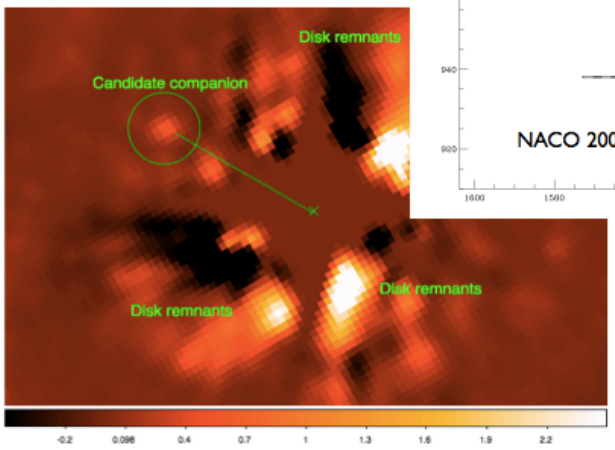
- IM Lupi (Sz82):
  - M0 WTTS
  - Very young star (~1 Myr)
  - Surrounded by optically thick disk (detected in submm, far-IR, imaged with WFPC2 and NICMOS)
  - Disk very massive (0.1 star) => unstable (Pinte et al. 2008)

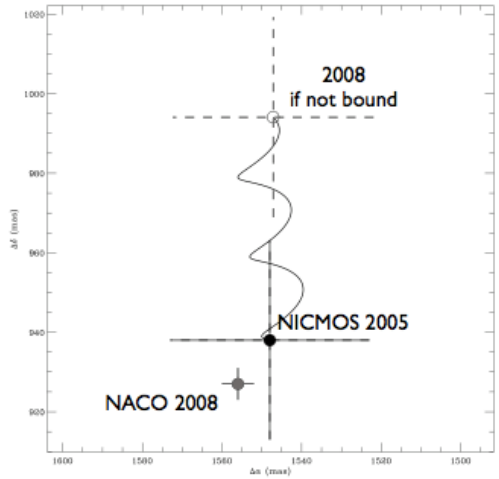


Candidate companion

- NACO FQPM image (2008)
- NICMOS 2005



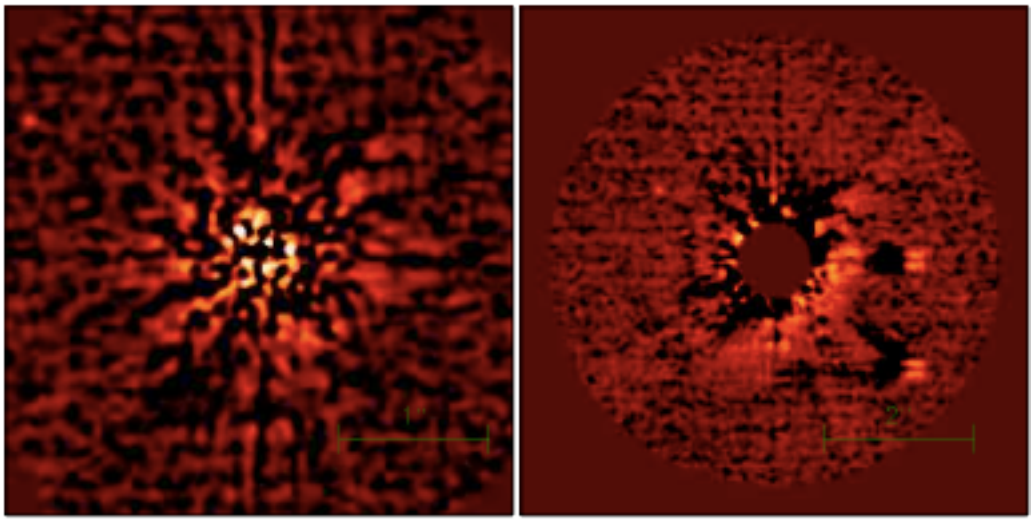


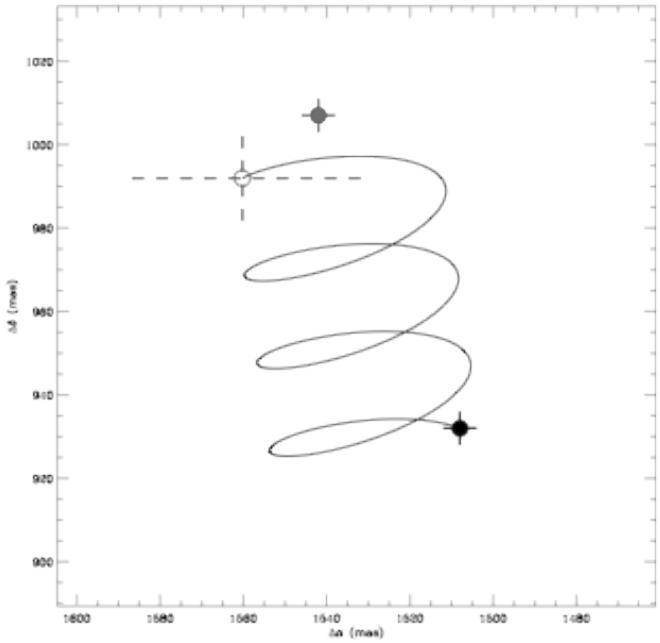


Candidate companion detected in 2008 by NACO (Mawet et al. 2012, in prep)

Long, very long follow-up

- New data in 2011, treated with home-made “disk-friendly pipeline”, adapted from damped-LOCI (Pueyo et al. 2011)

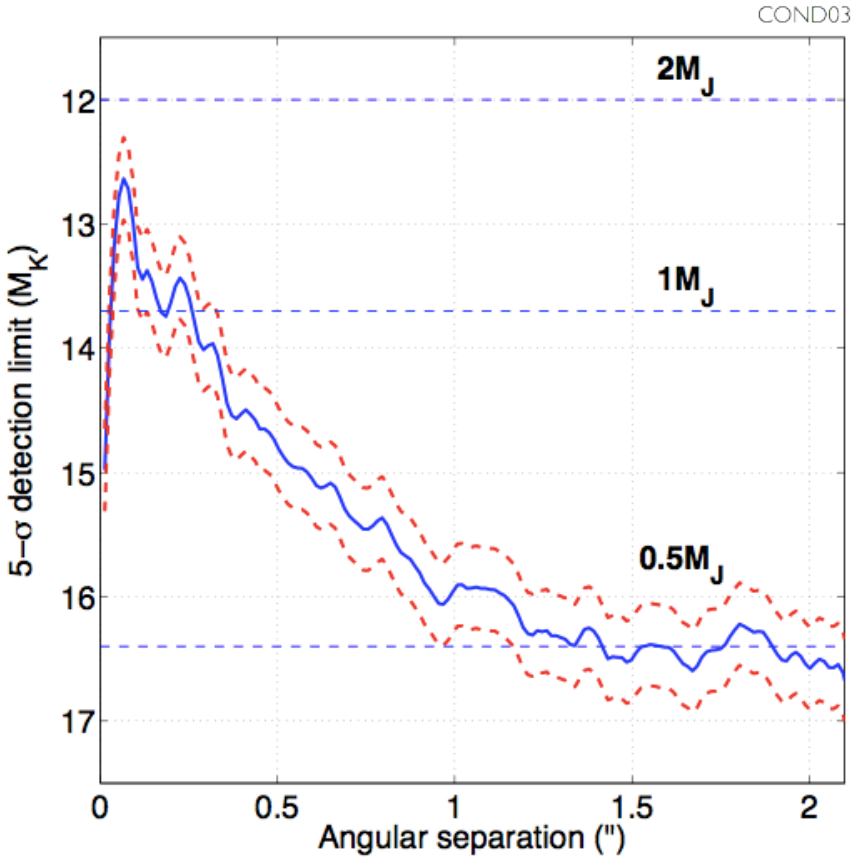




BUSTED !!! Sigh…

BUT…

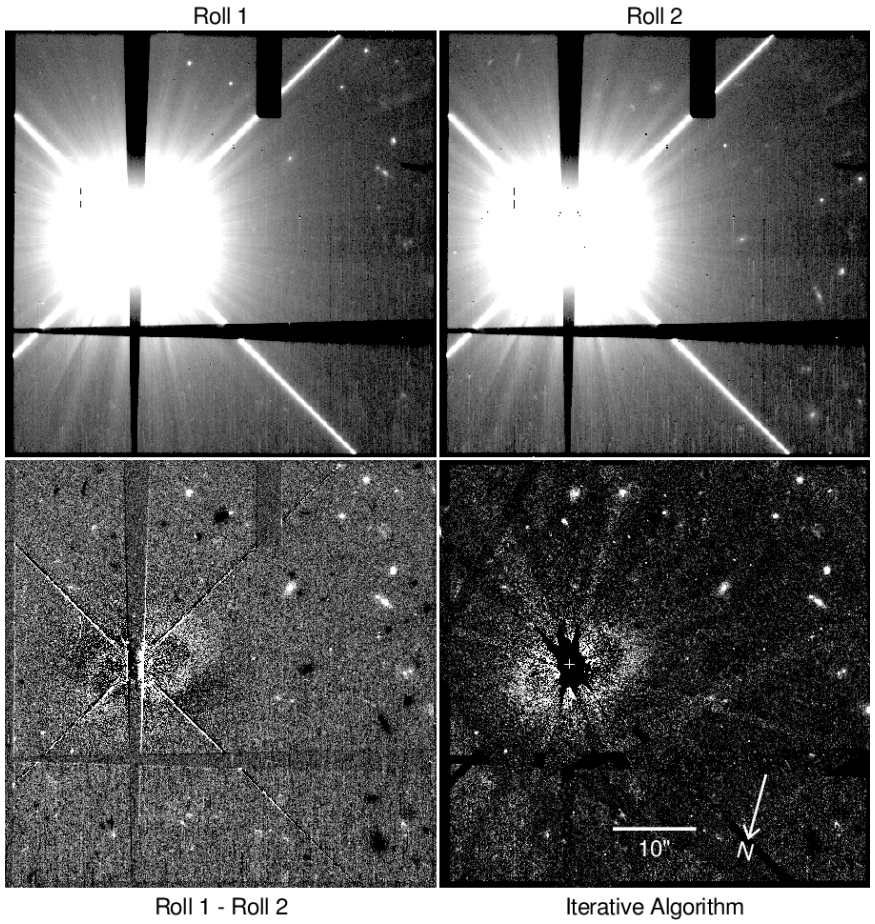
- Interesting constraints and lessons learned:
  - Don't trust hipparcos measurement > 100 pc, for young objects, and objects with disks
  - Absolute astrometric precision is a chimera
  - Relative astrometric precision between different instruments is a nightmare (e.g. HST-NACO, NIRC2-NACO, NICI-NACO)
  - Age determination is tricky, depends on distance



New promising candidates

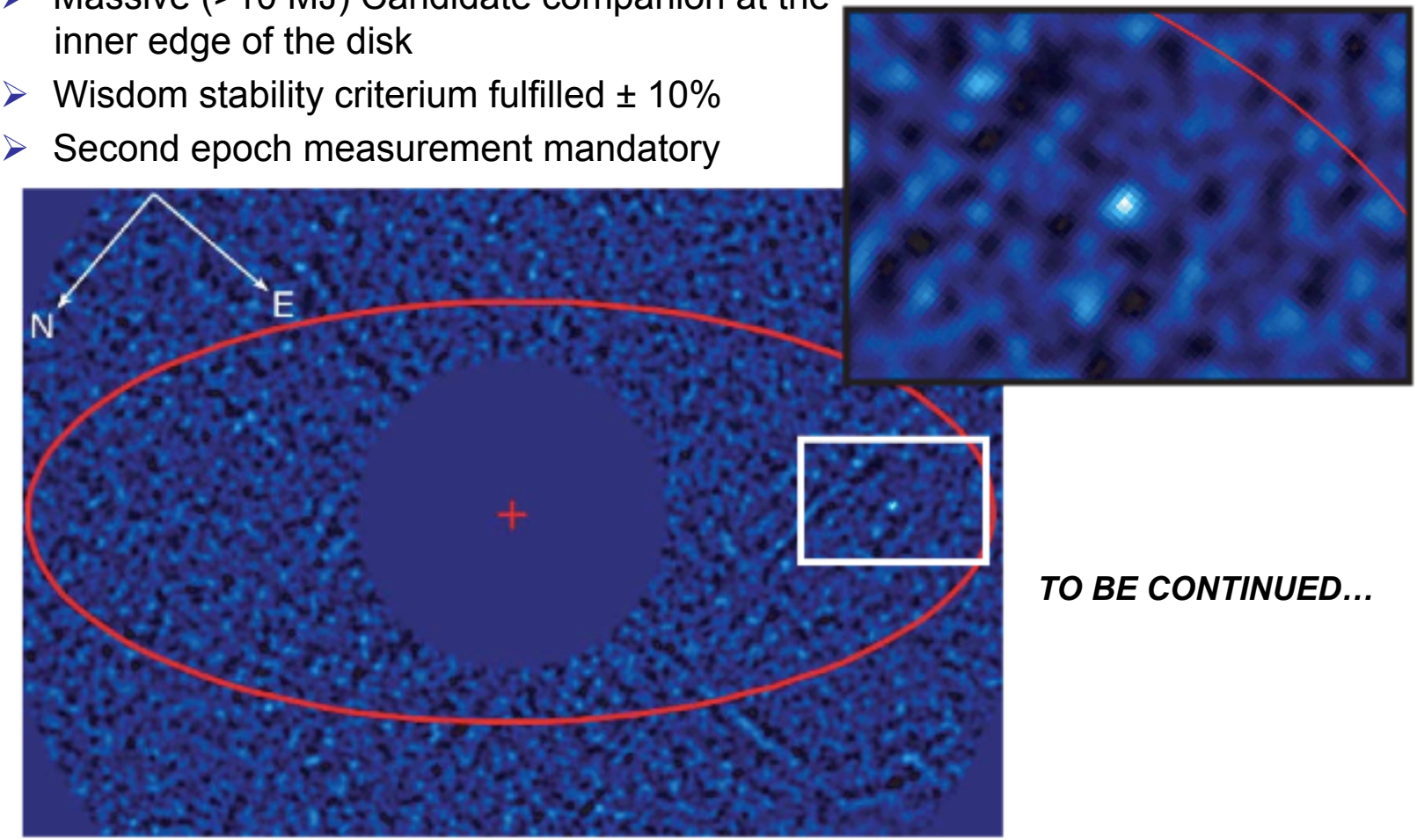
- John Krist's new HST/STIS disk (Krist et al. 2012, submitted):
  - Faintest disk ever imaged
  - G0 star (old ~2 Gyr)
  - Inclined ring
  - 24 AU offset from the star

Signpost of a shepherding body?



NACO follow-up in L-band

- Using the Lyot coronagraph / ADI:
  - Massive (>10 MJ) Candidate companion at the inner edge of the disk
  - Wisdom stability criterium fulfilled ± 10%
  - Second epoch measurement mandatory



TO BE CONTINUED…

Synergy ground-space

- Previous two examples

- Ongoing ground-based follow-up of stars with IR excess detected by Spitzer and WISE (Hinkley, Stapelfeldt, Morales, Serabyn, Werner, Mawet …)
  - Keck NIRC2
  - Palomar PHARO
  - NACO L-band
  - Soon VISIR (2 nights in April) => Disk imaging at N-band

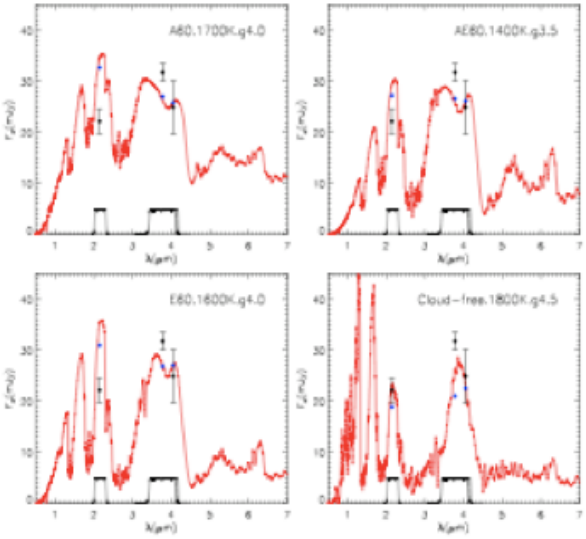
Future of NACO

- NACO is a very unique instrument
  - Only IR WFS in the SH
  - Only L-band high contrast imager in SH!
- Its fate is the hands of the STC
  - Trade-off:
    - Pressure from second-generation instruments
    - High maintenance cost for a 10 year old instrument

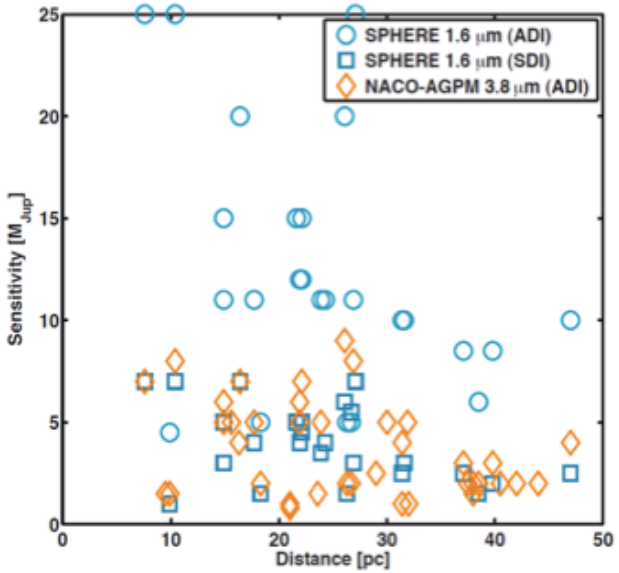
      VS
    - Galactic center science
    - Exoplanet imaging and characterization in L and M band

Still a lot of potential!

- 1- Provide complementary wavelength coverage to SPHERE
- 2- The L-K/H/J colors provide the most important photometric lever to characterize exoplanets atmosphere
- 3- Strehl naturally higher, and planet/ star contrast more favorable



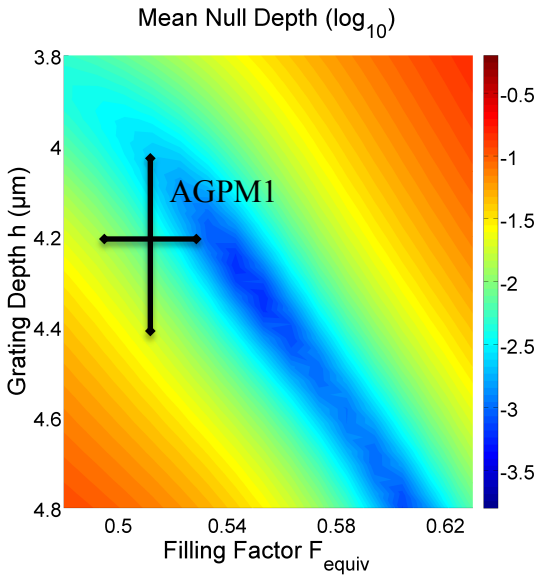
Currie et al. 2011

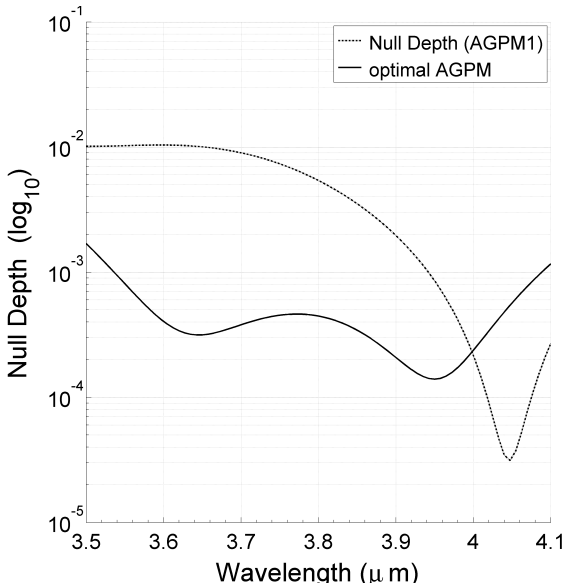


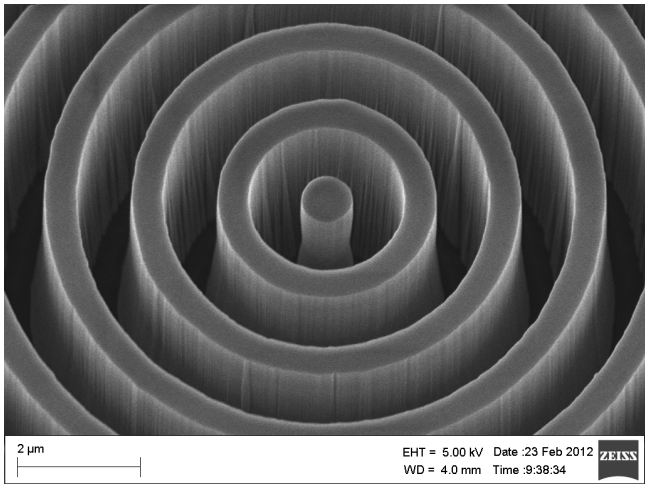
Expected performance of SPHERE and L-band coronagraphy in terms of planetary mass detectable around the nearest K- and M-dwarfs located in young moving groups (Absil, Hanot, ULg).

L-band VVC for NACO

- Potential window of opportunity in the fall
  - Development led by Ulg, Swedish technology:
    - C. Delacroix, S. Habraken, M. Karlsson, O. Absil, C. Hanot, J. Surdej, D. Mawet

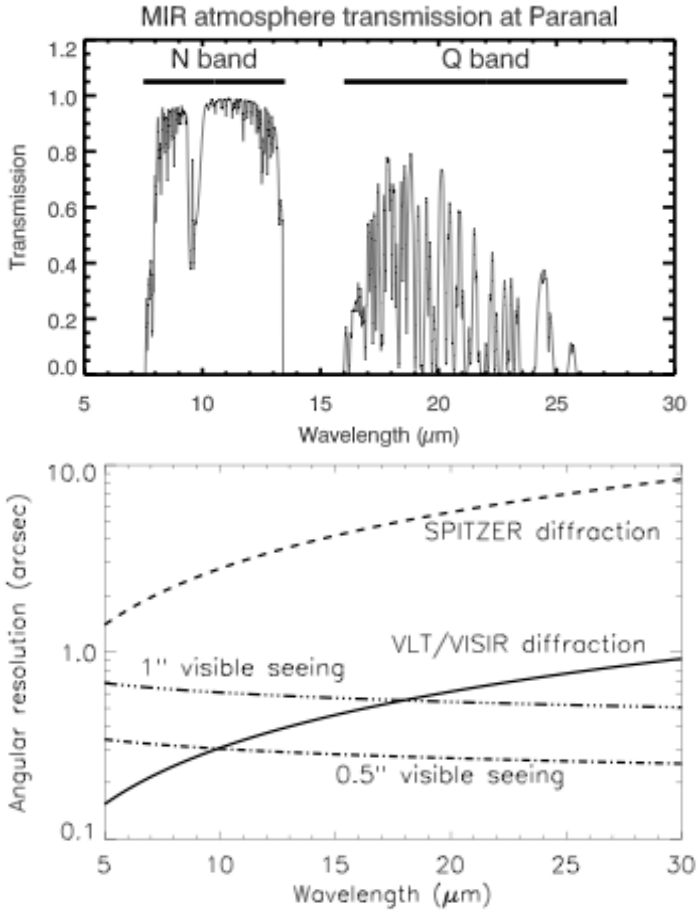


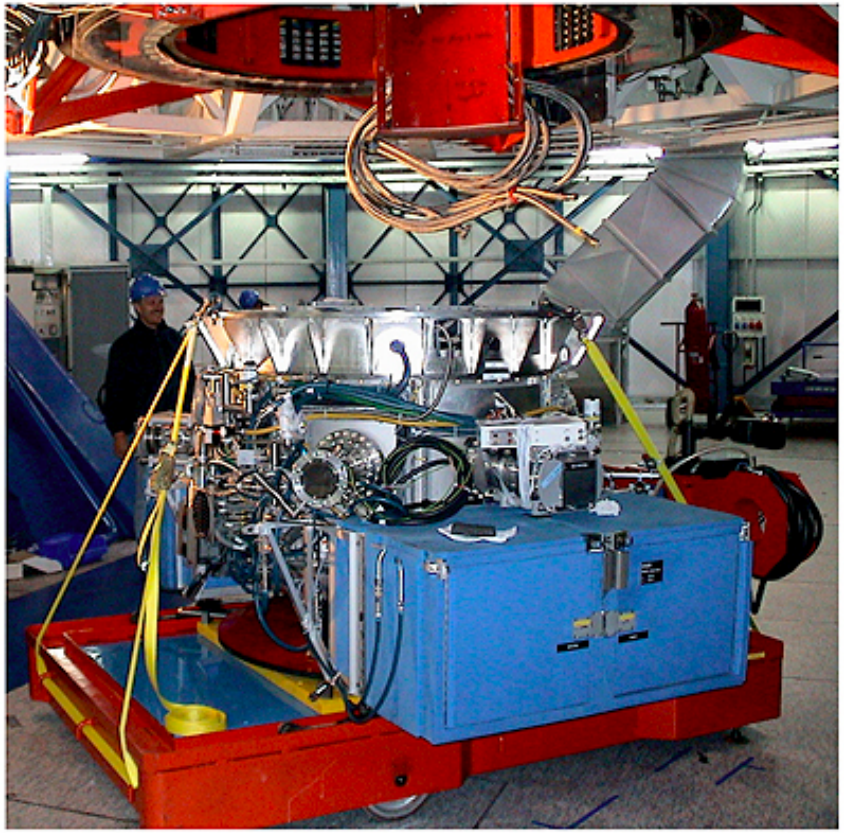




Mid-IR from the ground: VISIR

- Mid-IR from the ground

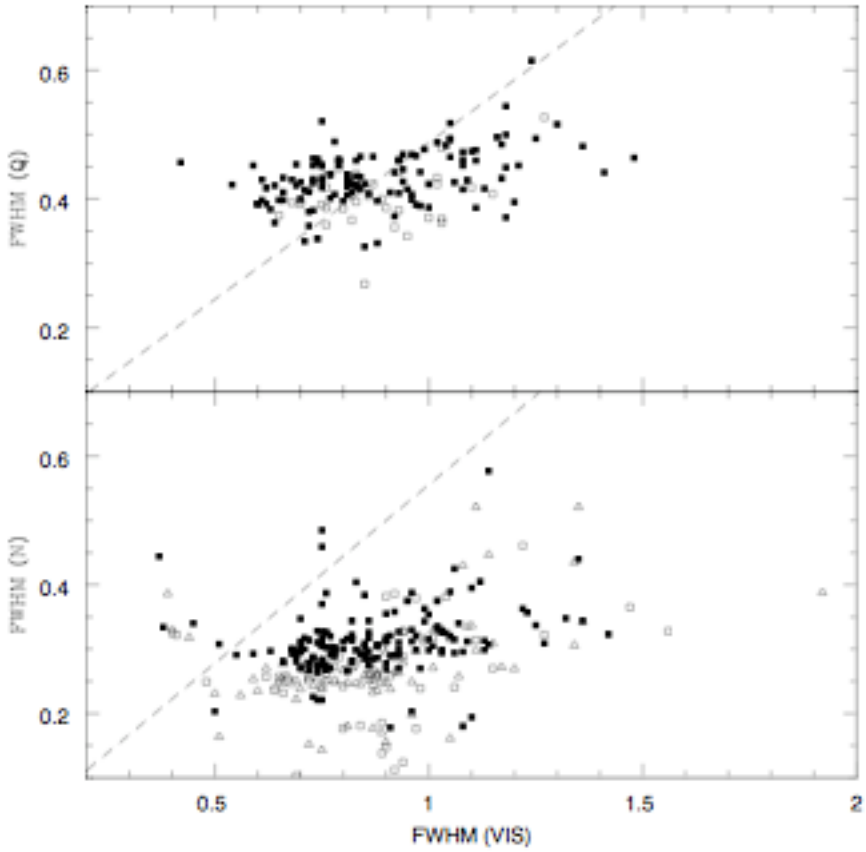




VISIR under the Cassegrain Focus of the 8.2-m VLT Melipal Telescope

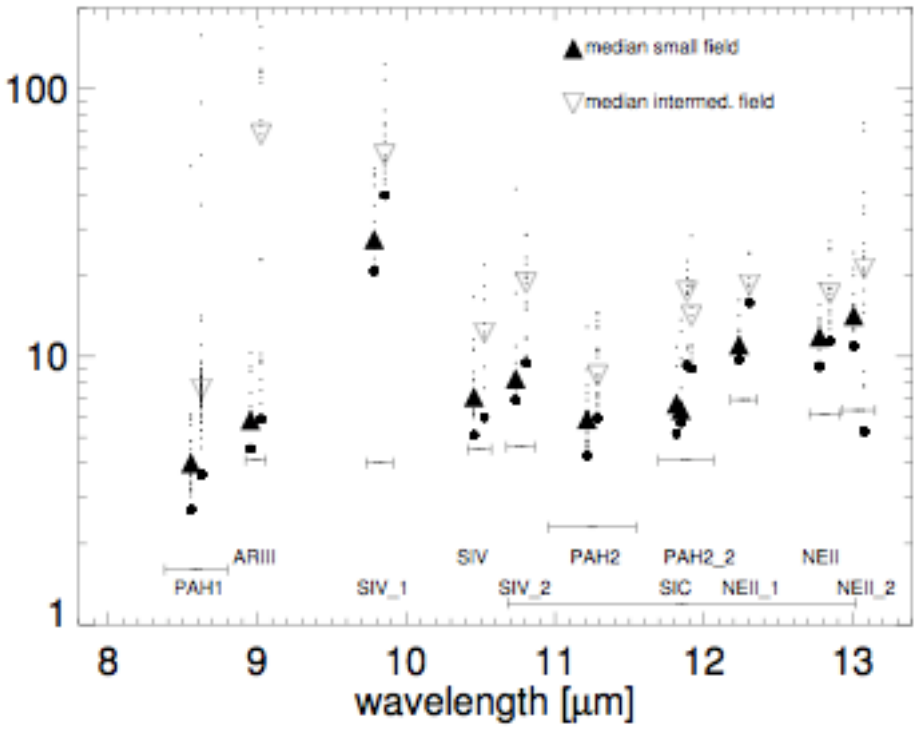
ESO PR Photo 16a/04 (12 May 2004)

IQ and Sensitivity of VISIR



Measured image Quality

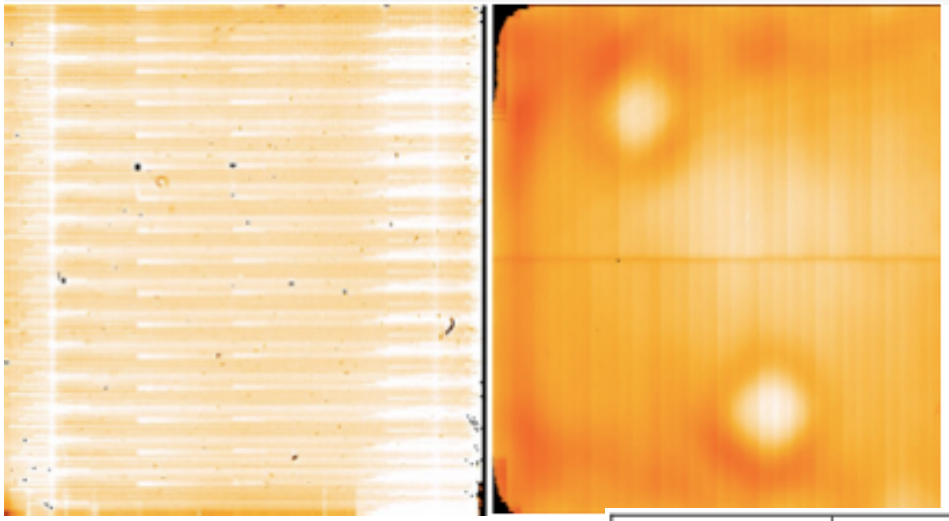
N-band senstivity



VISIR+

- New detector: 1Kx1K, less noise
- New prism:
  - With new detector => whole N band in one go
- Water Vapor monitor
- New modes:
  - MIRI's FQPM (10.4 and 11.5 μm)
  - VVC (AGPM, effort led by Ulg)
  - Sparse – Aperture Masking

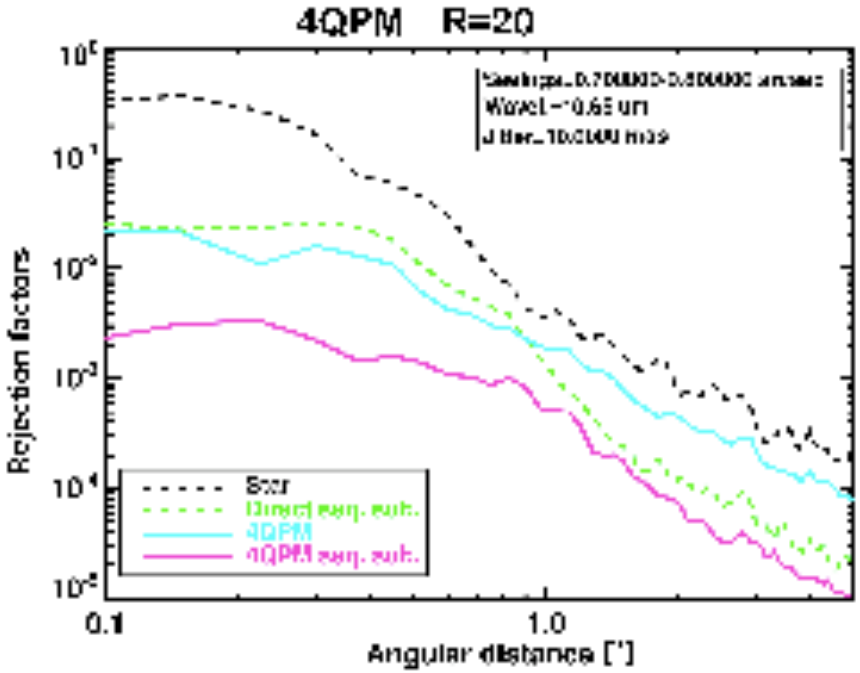
New AQUARIUS detector



Parameter	VISIR Instrument	TIMMI2 Instrument	AQUARIUS	HAWAII-2RG
Manufacturer	Boeing/DRS	Raytheon	Raytheon	Teledyne
Material	Si:As	Si:As	Si:As	HgCdTe
Array size [pixels]	256x256	320x240	1024x1024	2048x2048
Pixel size [µm]	50	50	30	18
Unit cell format	Direct Injection	Direction Injection	Source Follower per Detector	Source Follower per Detector
Temperature [K]	6	6	6	70
Outputs	16	16	64	32
Spectral Response [µm]	5-28	5-28	5-28	0.6-5
Well Capacity [electrons]	2E6/20E6 (switchable)	10E6/30E6 (switchable)	1E6/11E6 (switchable)	1E5
Noise [e rms]	300/2000 e rms	1000/3000 e rms	100/1000 e rms	< 10 e rms
Dark Current [e/pixel/s]	2500 e	100 e	1 e	1 e
Frame Rate [Hz]	100	100	120	1
QE	>50%	>40%	>50%	>90%
Year	1990s	1990s	2010	2005
Issues	Cosmetics	Cosmetics		None

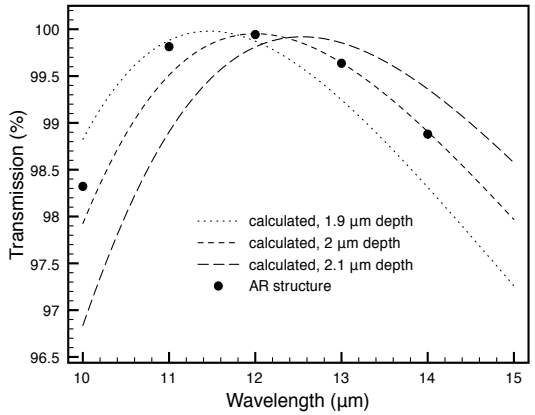
Coronagraphy

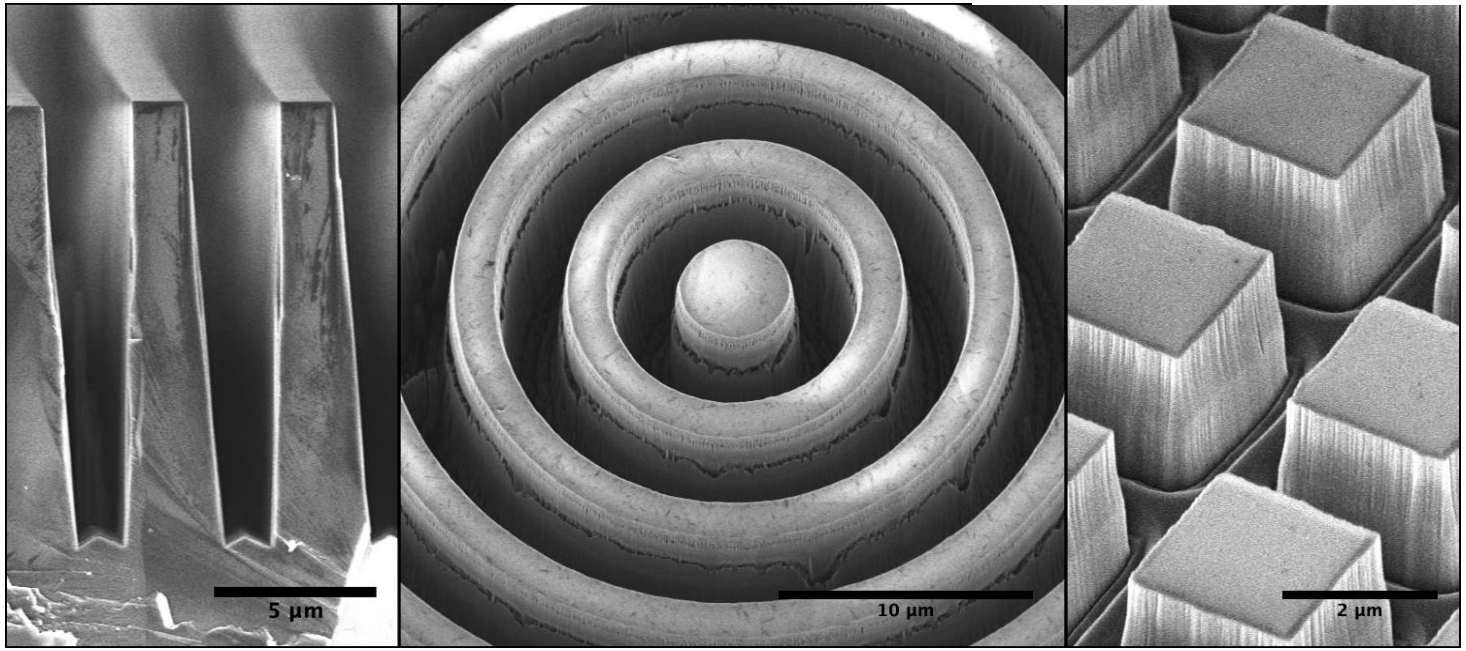
- FQPM of MIRI (made out of Ge)
- VVC-AGPM (made out of Diamond)
- Field tracking and ADI for PSF subtraction



First VVC @ N-band

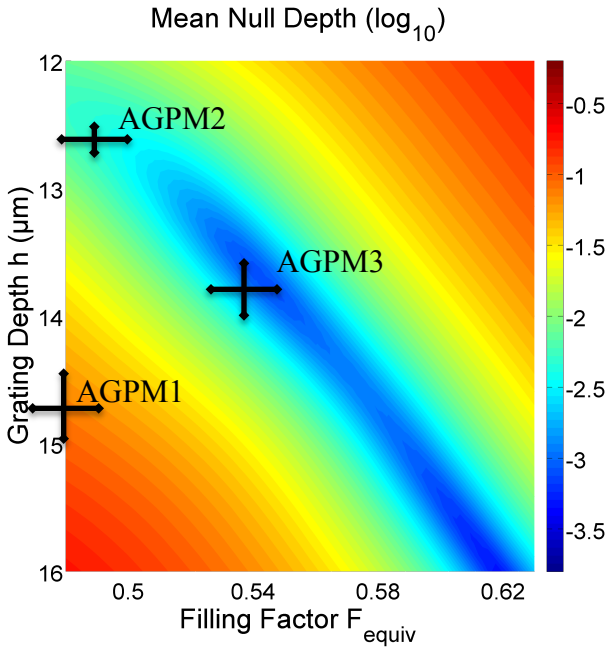
- Micro-fabrication (nano-imprint lithography, reactive ion etching), metrology (SEM, AFM, cleaving/cracking!)
- LEFT : High aspect ratio subwavelength grating
- Depth ~13.7 µm
- Period ~4.6 µm
- Line width (top) ~1.8 µm
- RIGHT : Antireflective structure (2.62x2µm) etched on the backside of the AGPM, allowing a total tansmittance between 89 and 95% over the band.

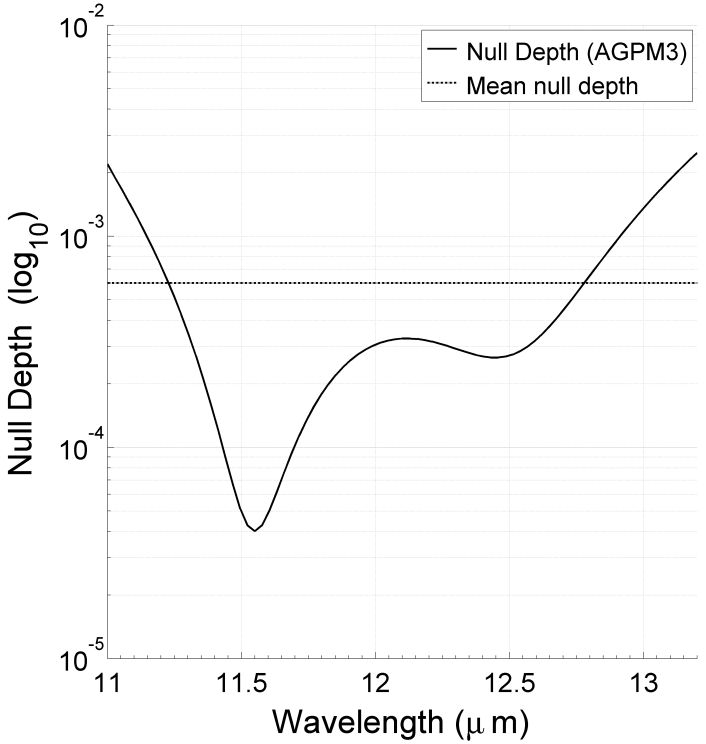




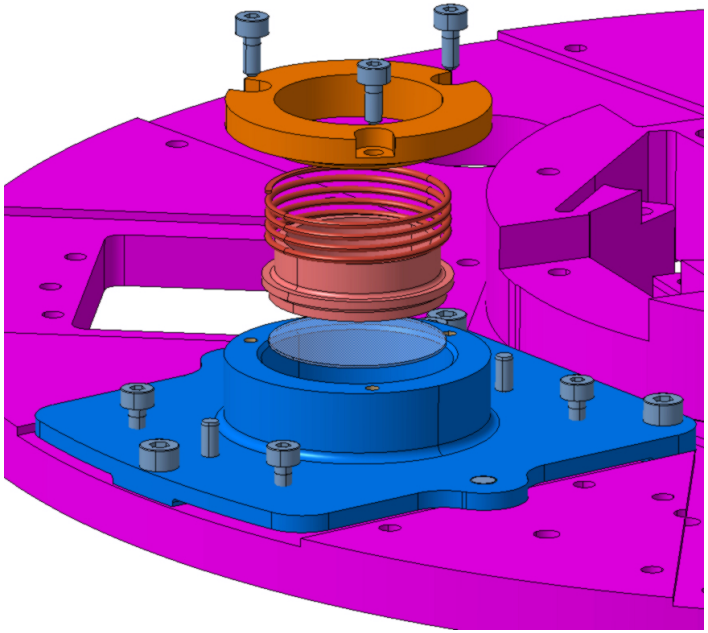
AGPM… #3!

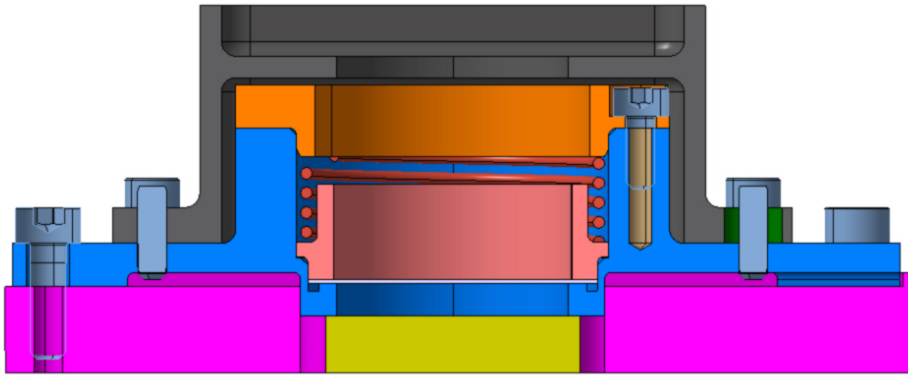
- Upper N-band 11-13.2 µm
- 3 components (AGPM1,2,3) etched with slightly different specifications
  Best performances: AGPM3 with a Null Depth ~6x10-4 (contrast ~3x10-6 @ 2λ/D)
- AGPM 3 is planned to be installed on VISIR (upgrade in may-august 2012) and tested on 22nd of September 2012 !!





Mount

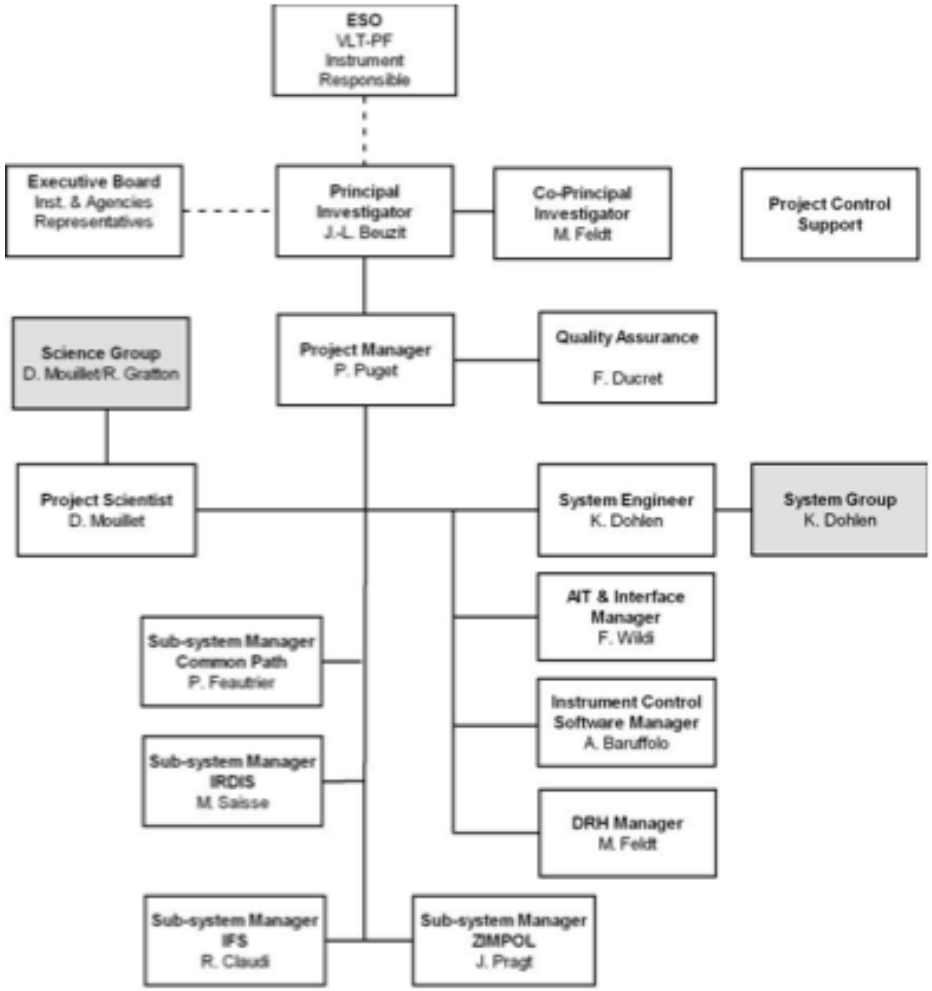




Spectro-Polarimetric High-Contrast Exoplanet Research

Institute/People

- CNRS/LAOG
- CNRS/LAM
- CNRS/LESIA
- CNRS/LUAN
- ONERA
- MPIA
- INAF/Padova Obs
- Obs de Geneve
- ETH Zurich
- NOVA
- ASTRON



Science Goals

- High contrast imaging down to planetary mass companions
- Investigate large target sample: statistics, variety of stellar classes, evolutionary trends
- First order characterization of the atmosphere (Clouds, dust content, Methane, water absorption, Effective temperature, radius, dust polarization)

Understand the planetary system origins

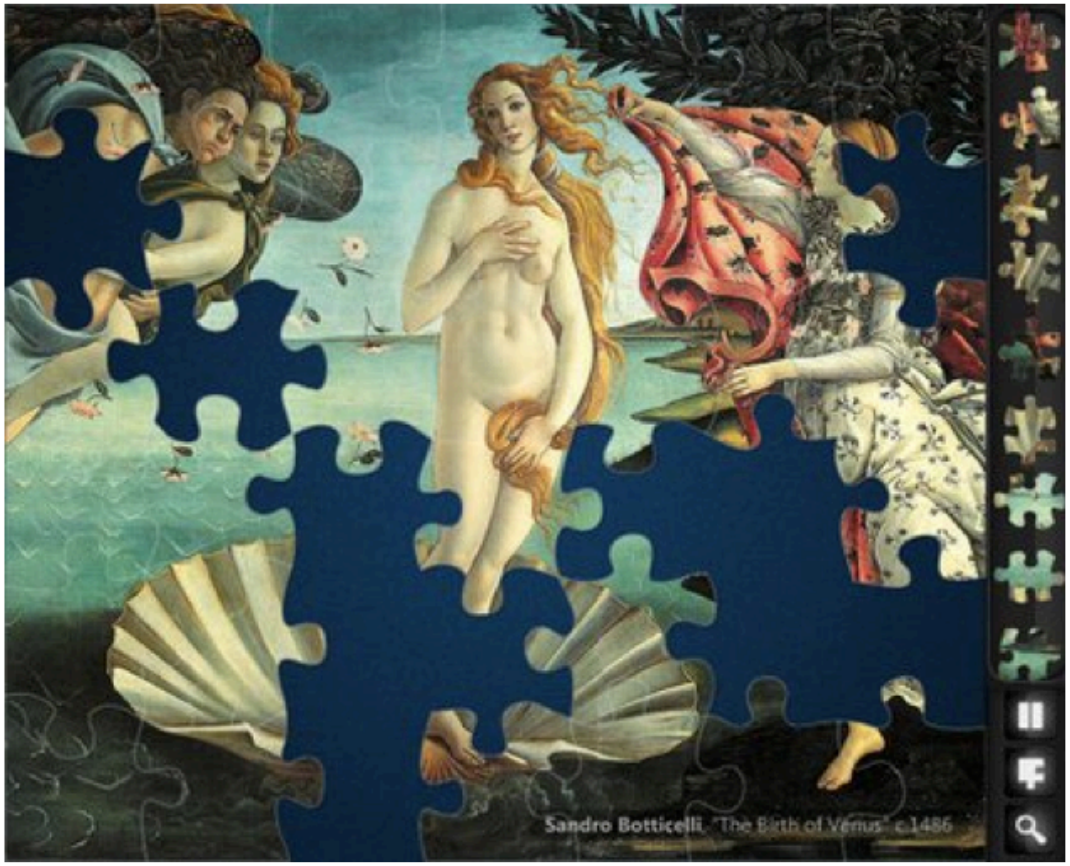
The whole picture

(*adapted from J. Trauger*)

Transit

RV

Age



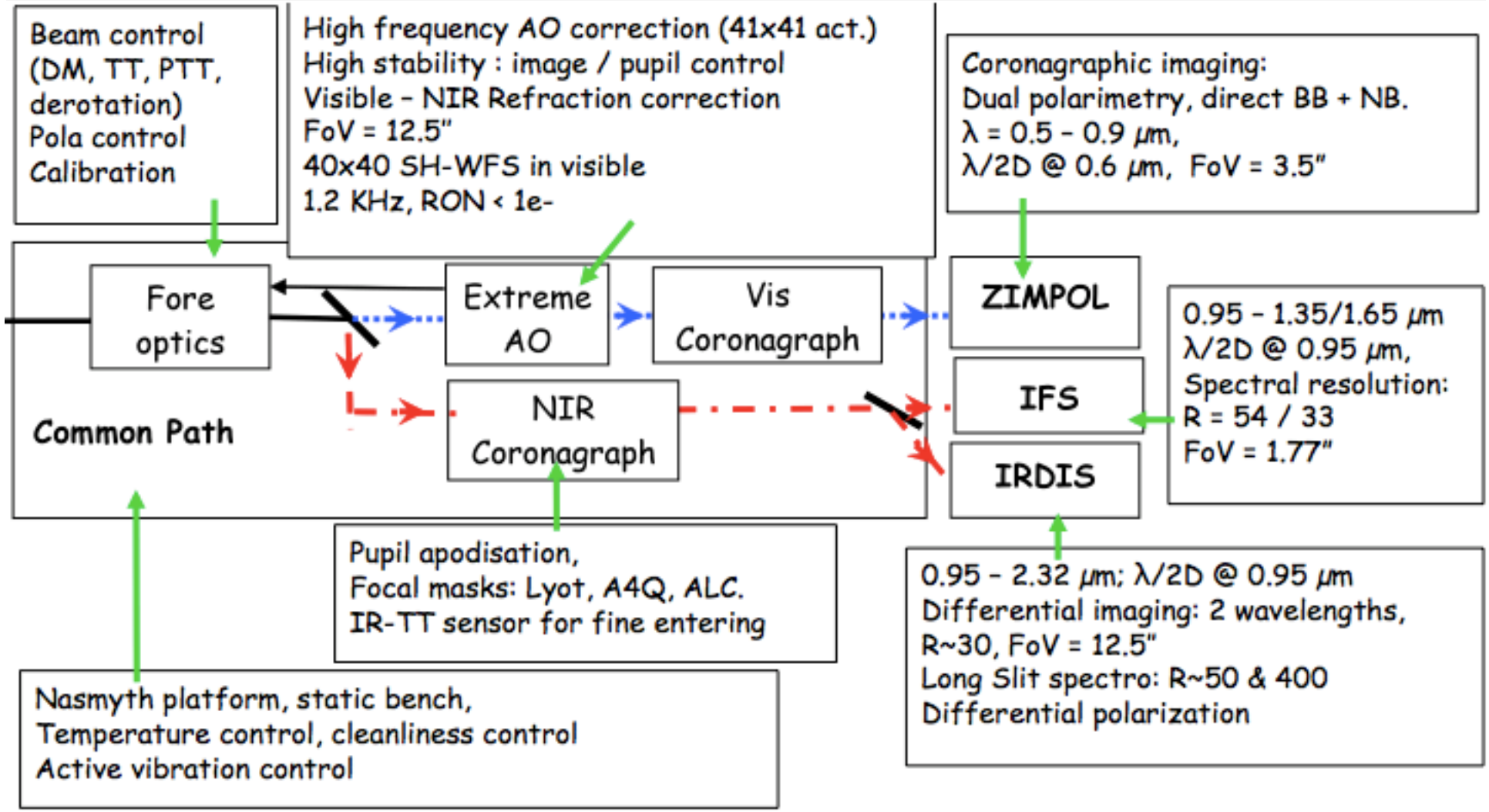
SMA

μ-lens

DI

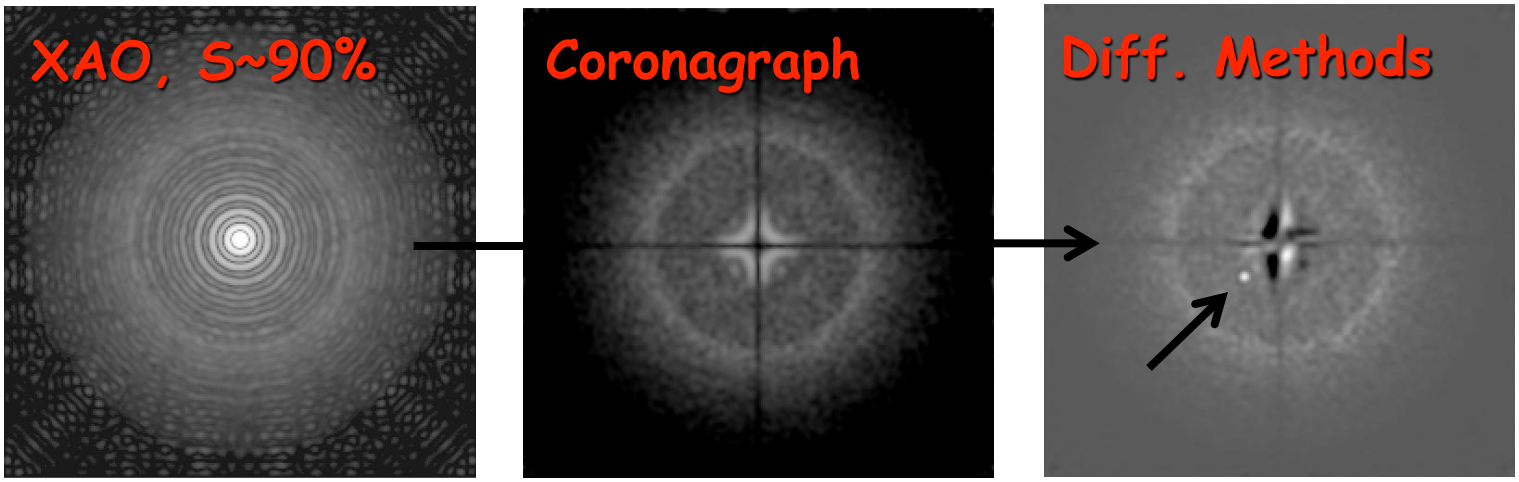
I

Concept overview



Work Flow

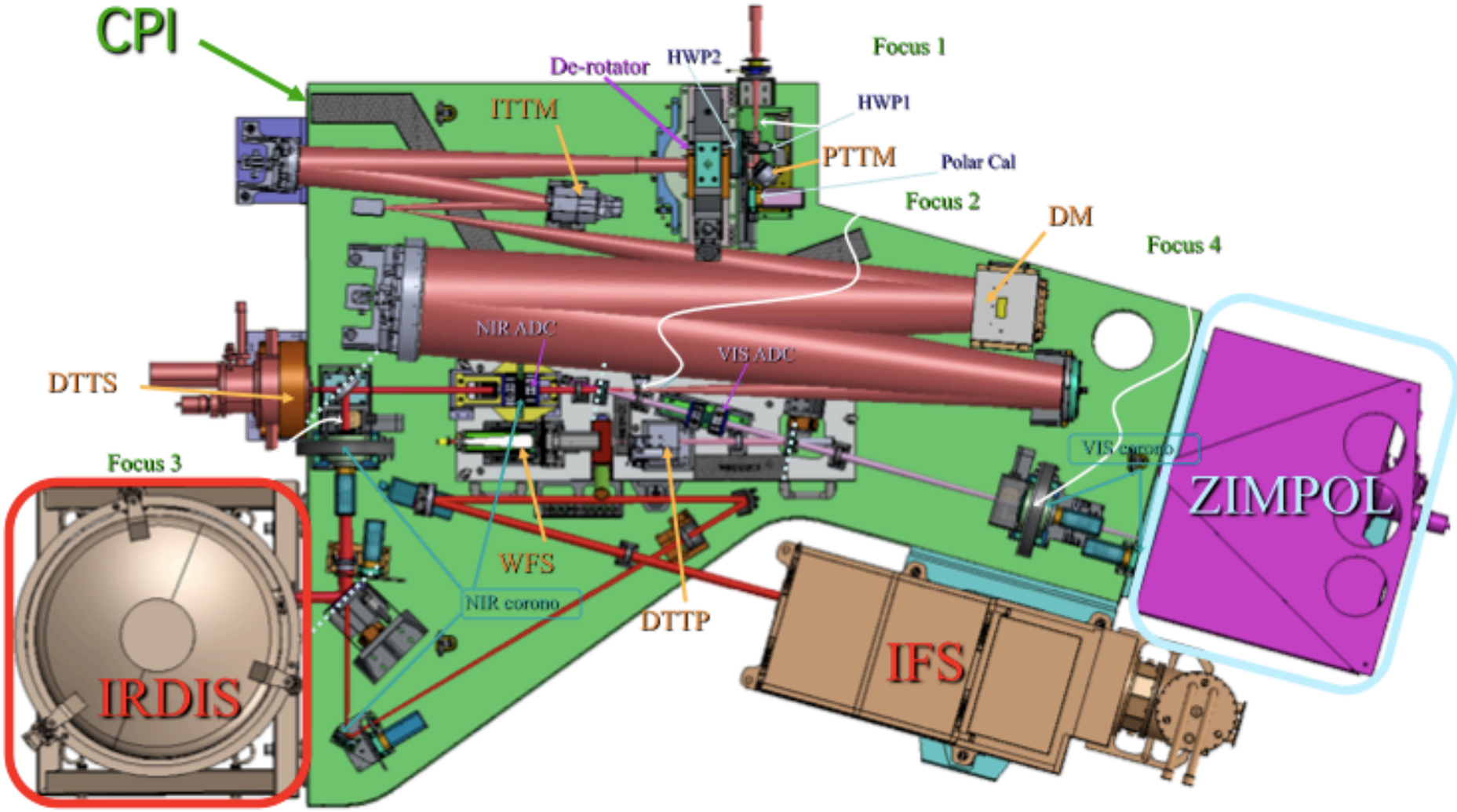
- ExAO – coronagraphy – differential imaging
- Differential imaging: DBI, SDI, PDI / ADI



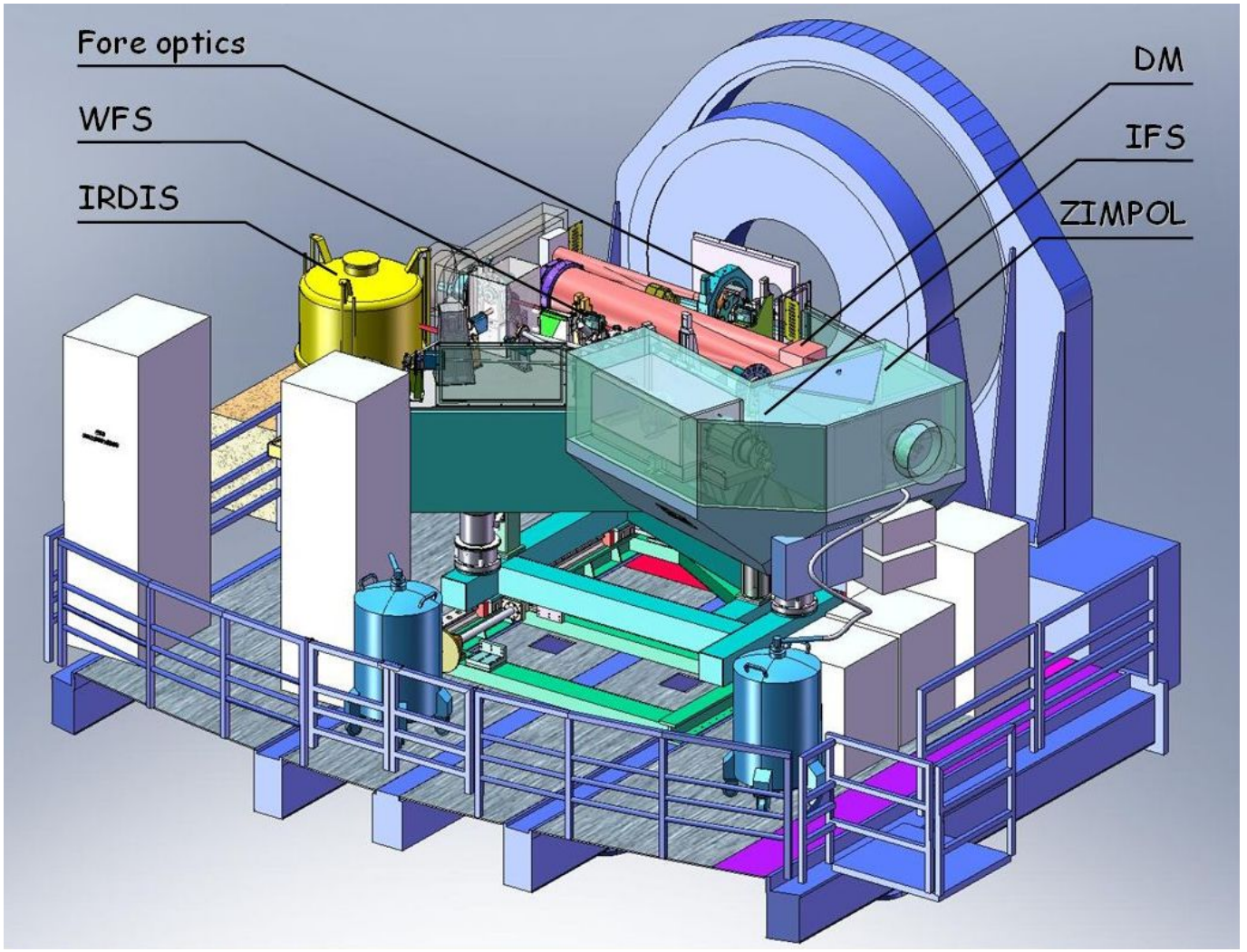
Modes summary

	ZIMPOL	IRDIS	IFS
FoV	Sq 3.5" (instantaneous) Up to 4" radius (mosaic)	Sq 11"	Sq 1.77"
Spectral Range	0.5 – 0.9 µm	0.95 – 2.32 µm	0.95 – 1.35/1.65 µm
Spectral information	BB, NB	BB, NB Slit spectro: 50/400	50 / 30
Linear Polarisation	Simultaneous on same detector, x 2 arms, exchangeable	Simultaneous dual beam, exchangeable	x

Implementation

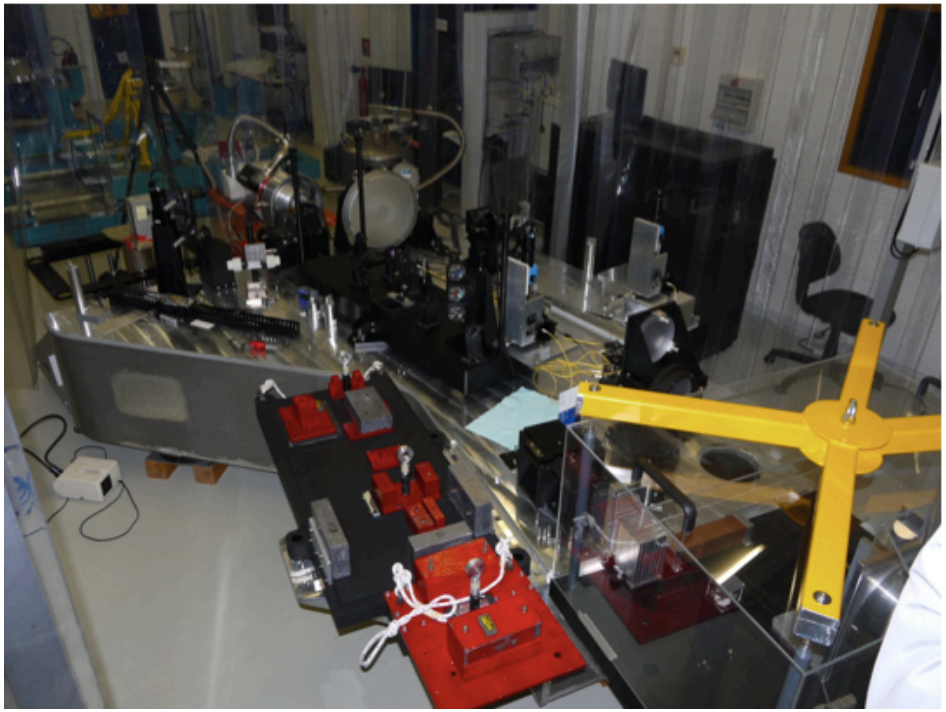


At the telescope



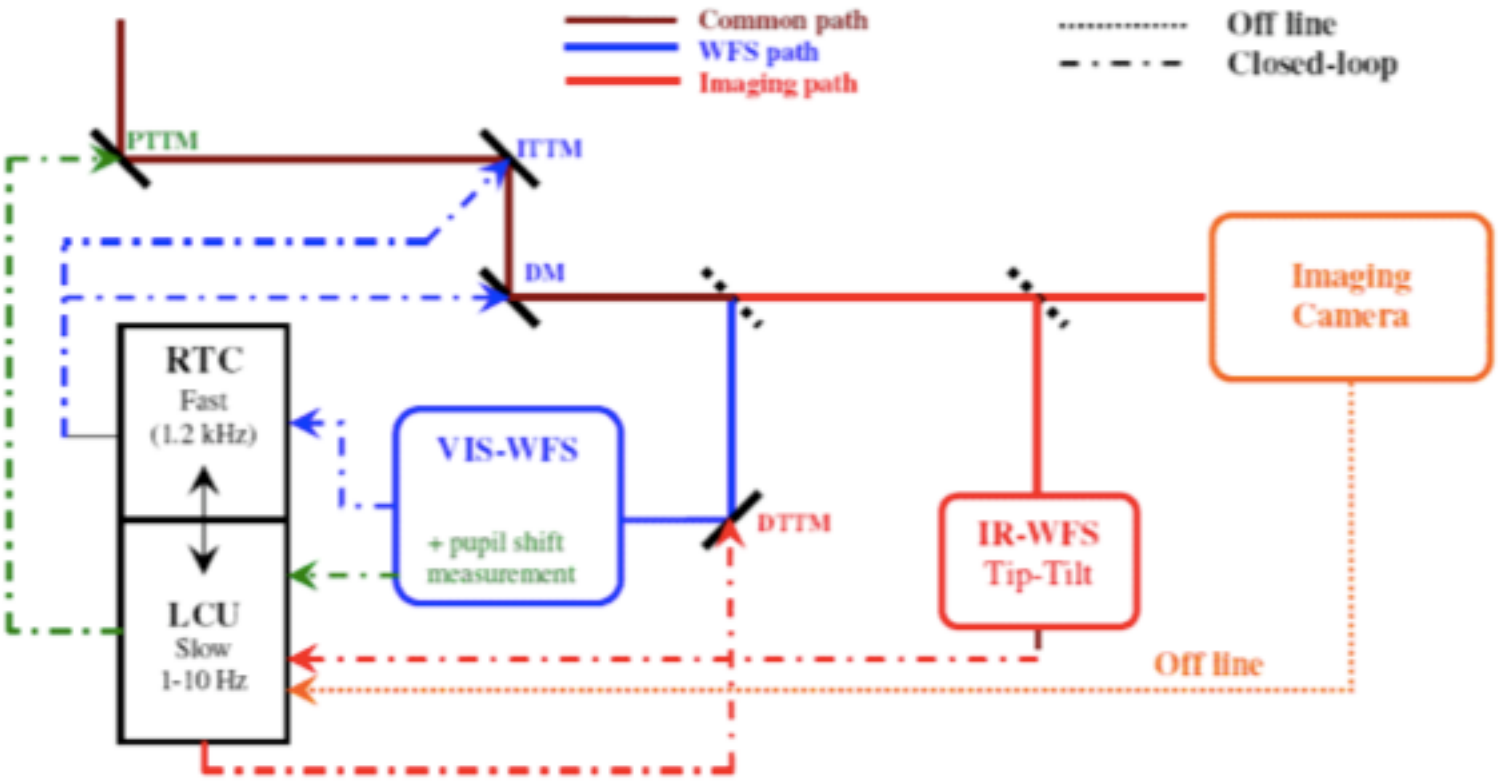
CPI

- Common path infrastructure
- Contains the coronagraphs (Lyot, APLC, FQPM), all the foreoptics



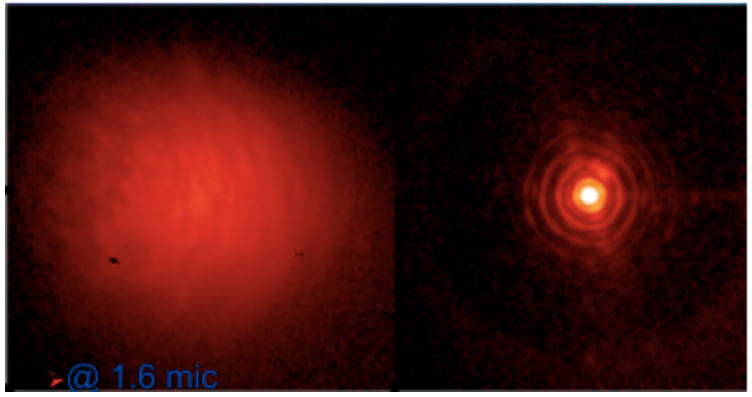
Mode	Static wavefront error from VLT Nasmyth focus	
Main survey mode , 950-1350 to IFS, H-band to IRDIS	<67nm to IRDIS	<69nm to IFS
Extended IFS mode, 950-1700 to IFS, Ks to IRDIS	<69nm to IRDIS	<69nm to IFS
IRDIS only	<68nm to IRDIS	
All NIR science modes (100% VIS on WFS)		< 65 nm to WFS
ZIMPOL broad band	<65nm to ZIMPOL	<65nm to WFS
ZIMPOL R-band	<65nm to ZIMPOL	<95nm to WFS

SAXO

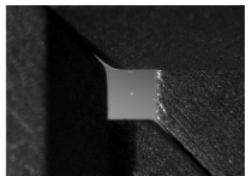

Common path
WFS path
Imaging path
Off line
Closed-loop
PTTM
ITTM
DM
Imaging Camera
RTC
Fast
(1.2 kHz)
VIS-WFS
+ pupil shift measurement
DTTM
IR-WFS Tip-Tilt
LCU
Slow
1-10 Hz
Off line

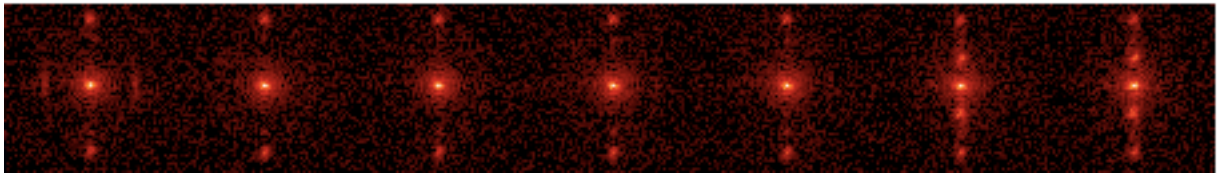
SAXO

- High-order Adaptive Optics system
  - 40x40 DM (Piezo-stack, CILAS)
  - 1.2 kHz visible WFS (41x41 SH)
- Recently closed the loop with turbulence generator:
  - >80% Strehl in H with 0”.65 seeing and 10 m/s wind



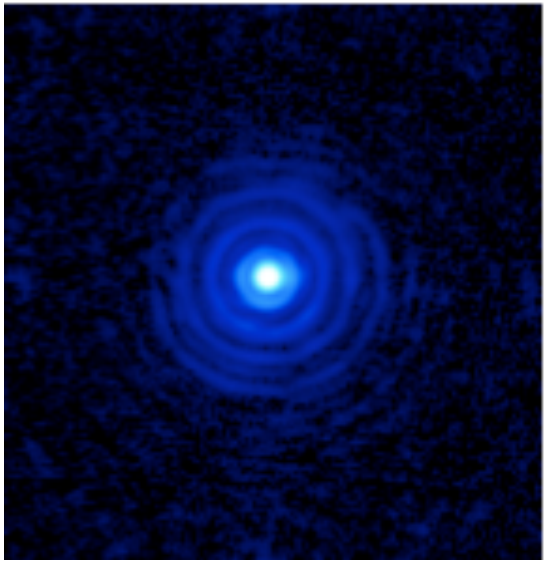
- Spatial filter validated in the lab

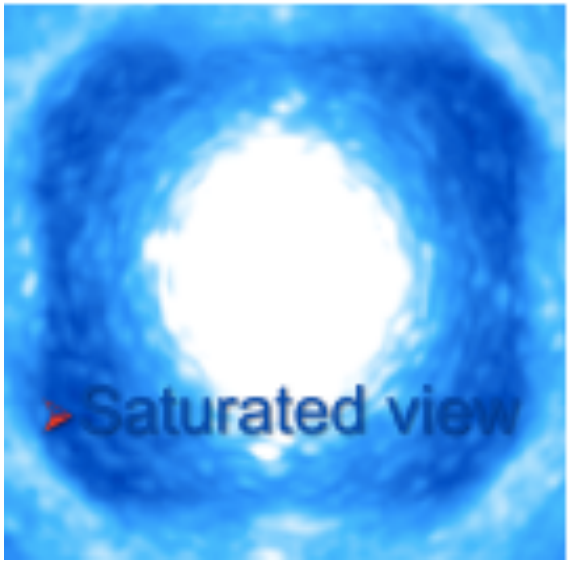




NCPA

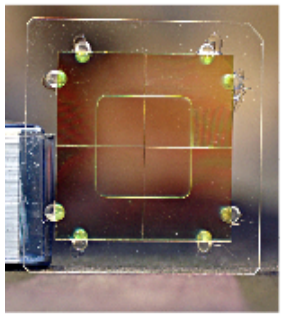
- 2-stage Focus diversity
  - EFC not the baseline but currently considered
- Down to a few nm rms
- PHILISOPHY: rely on stability of the platform (active damping system and passive thermal control)
- VISIBLE images:

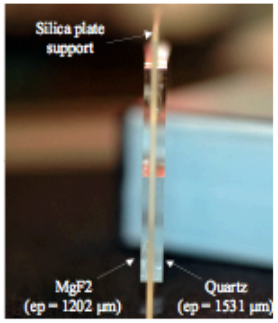


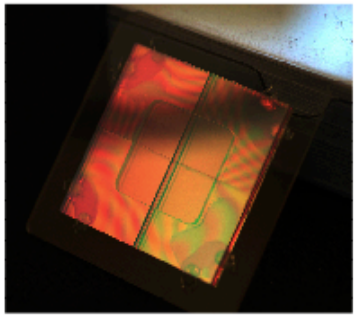


Coronagraphs

AFQPM



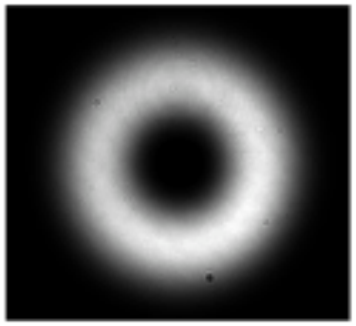




Pros:
IWA ~1 λ/d
Simple (no apodizer needed)

Cons:
Difficult to make achromatic
Phase transition lead to useful FoV loss
Sensitivity to central obscuration and low-order aberrations (tip-tilt)

(AP)LC

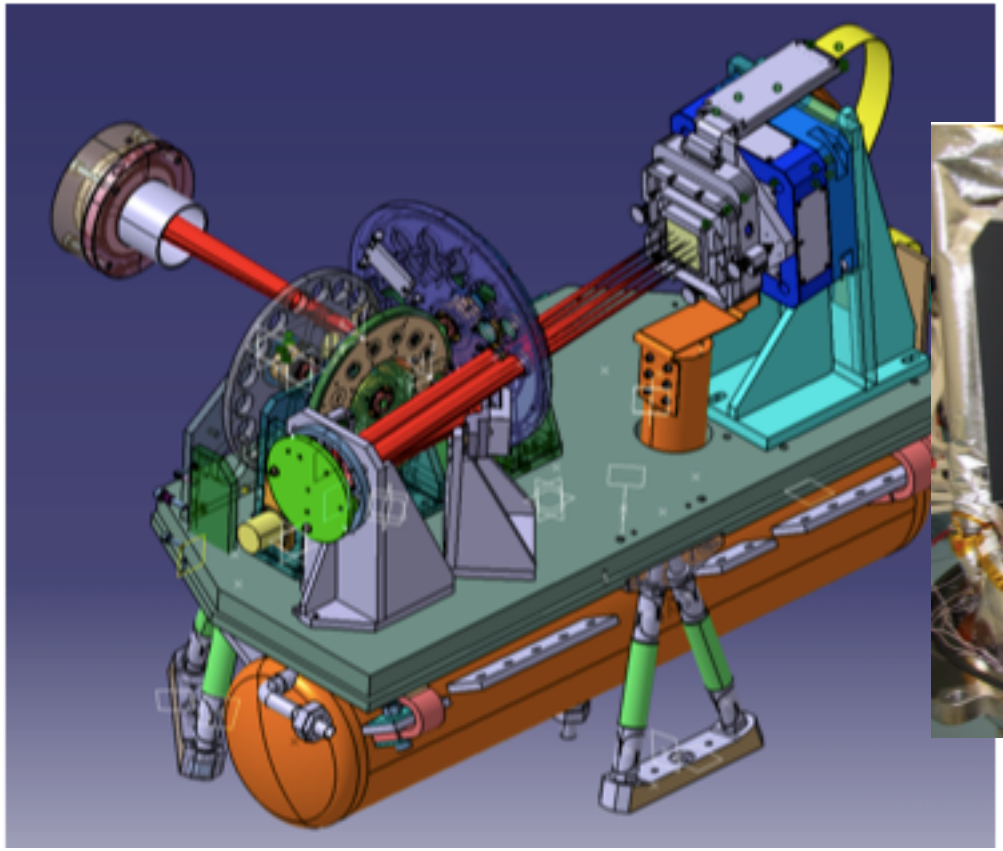


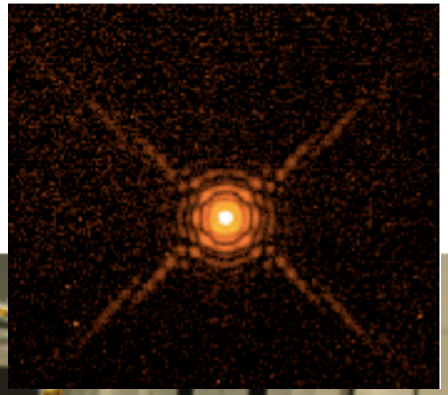
Pros:
Fairly achromatic
Fairly insensitive to central obscuration and tip-tilt

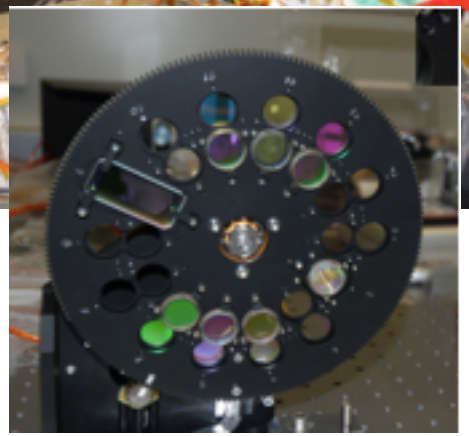
Cons:
IWA ~3-4 λ/d
Apodizer difficult to get right

IRDIS

- Dual-beam imager and spectrograph

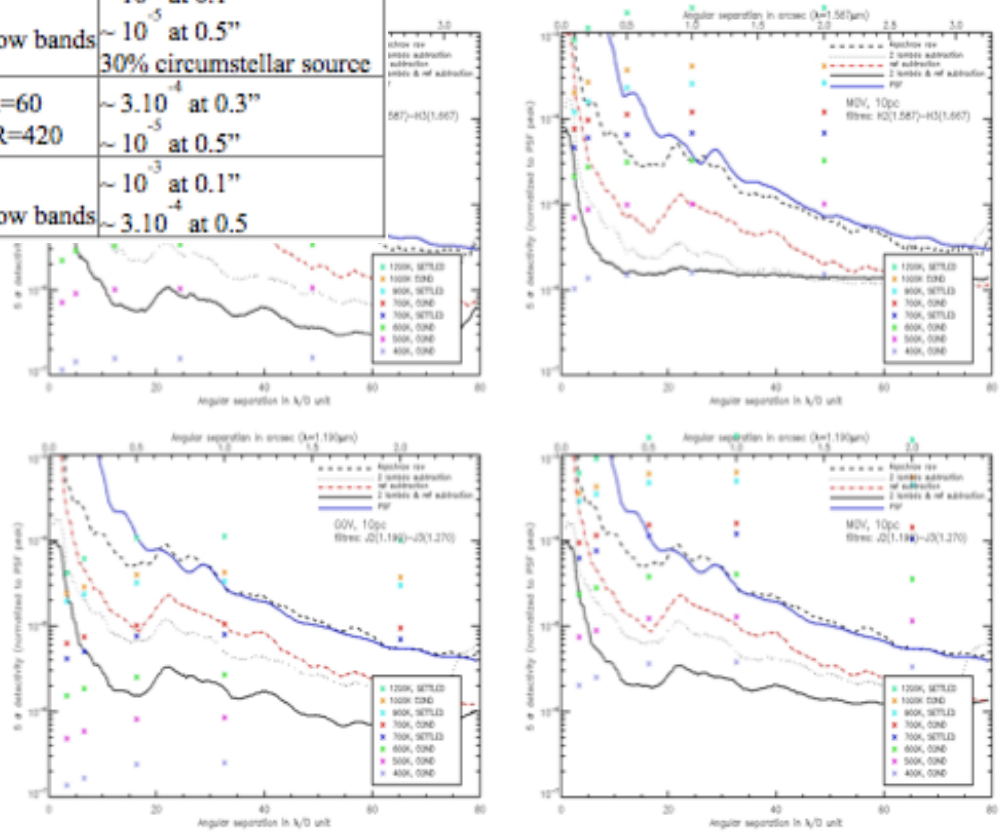






Modes and Expected Perf

Mode	Use Science case	Wavelength Bands	Rotator mode	Filters, Resolution	Contrast Performance (1h, SNR=5, H<6)
Dual Band Imaging	Survey mode (H only) Characterization of cool outer companions	Y,J,H,Ks	Pupil or field stabilized	6 pairs R=20-30	~ 10^{-5} at 0.1" ~10^{-6} at 0.5"
Dual Polarimetry Imaging	Reflected light on extended environment	Y,J,H,Ks	Pupil or field stabilized	4 Broad 10 Narrow bands	~ 10^{-4} at 0.1" ~ 10^{-5} at 0.5" 30% circumstellar source
Slit Spectroscopy	Characterization of not too faint companions	LRS : Y-Ks MRS: Y-H	Pupil stabilized	LRS : R=60 MRS : R=420	~ 3.10^{-4} at 0.3" ~ 10^{-5} at 0.5"
Classical Imaging	Environment with no spectral features	Y,J,H,Ks	Pupil or field stabilized	4 Broad 10 Narrow bands	~ 10^{-3} at 0.1" ~ 3.10^{-4} at 0.5

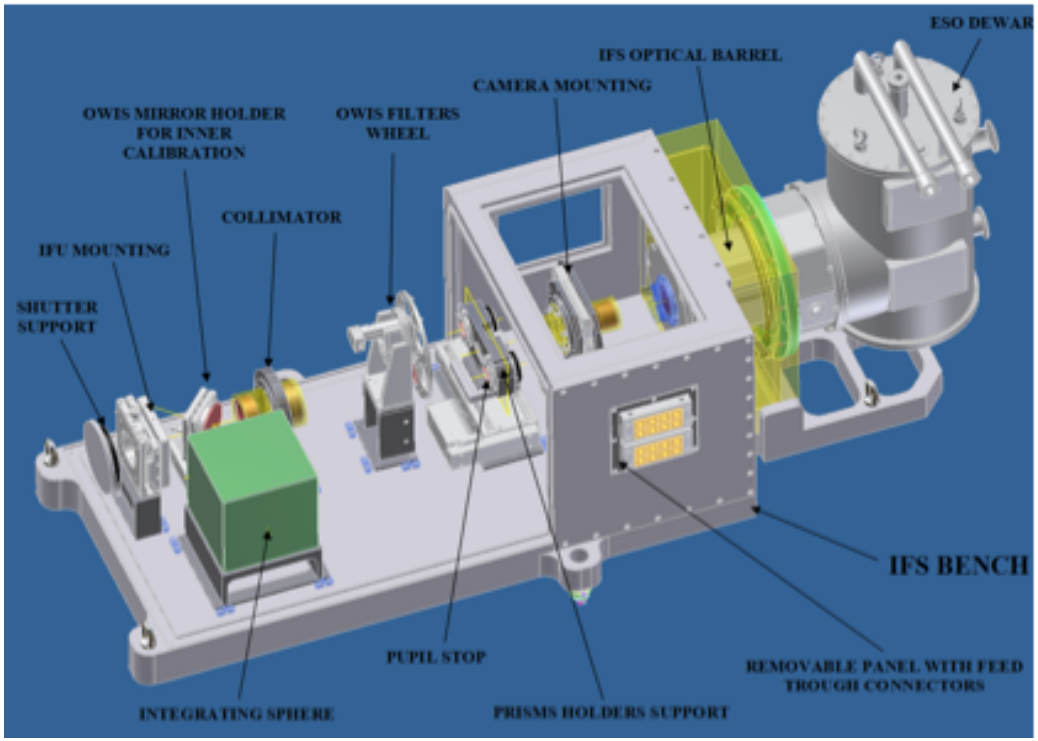


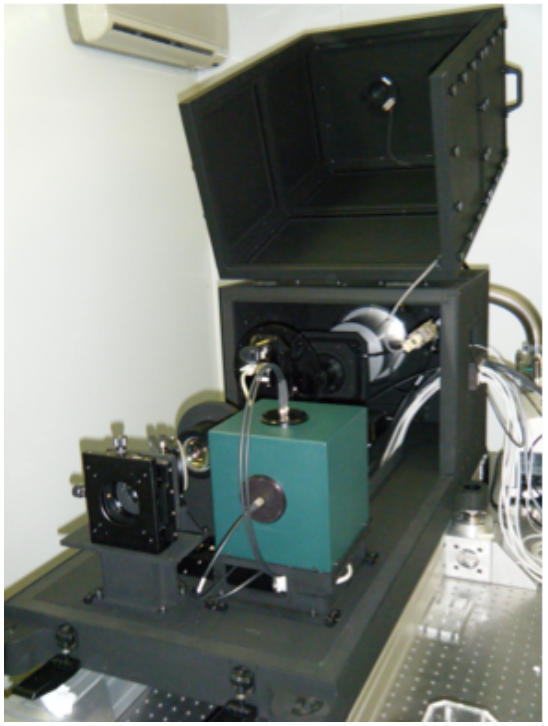
Boccaletti et al. 2008

Differential aberrations < 10 nm, really close to The 5 nm goal!

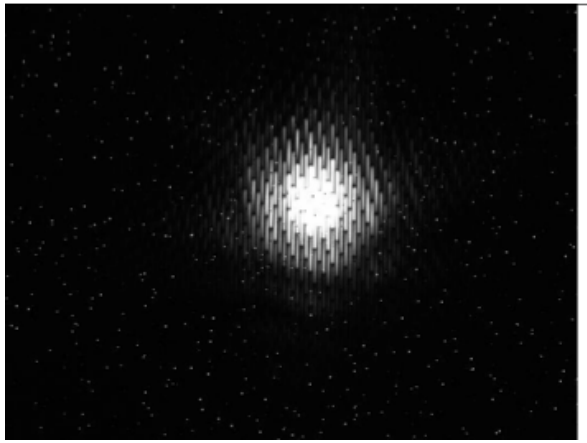
IFS

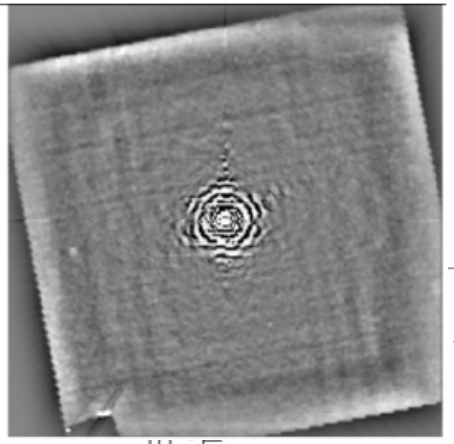
- Integral Field Spectrograph



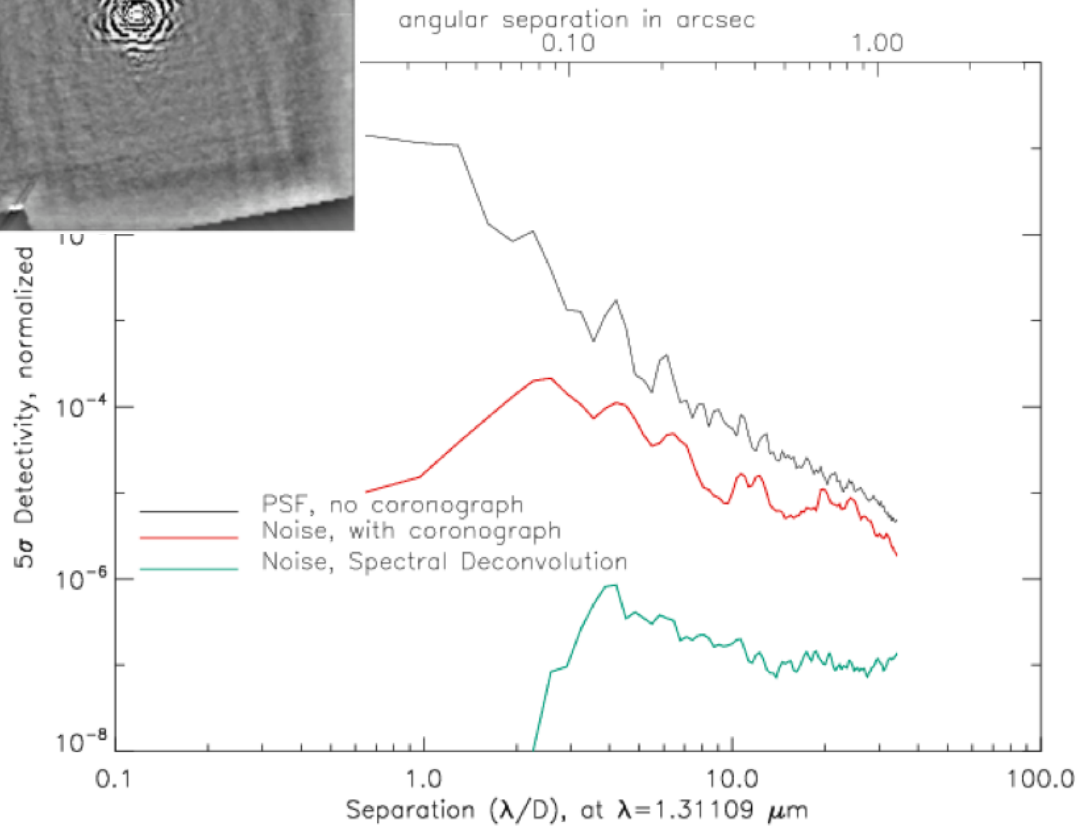


Expected Perf



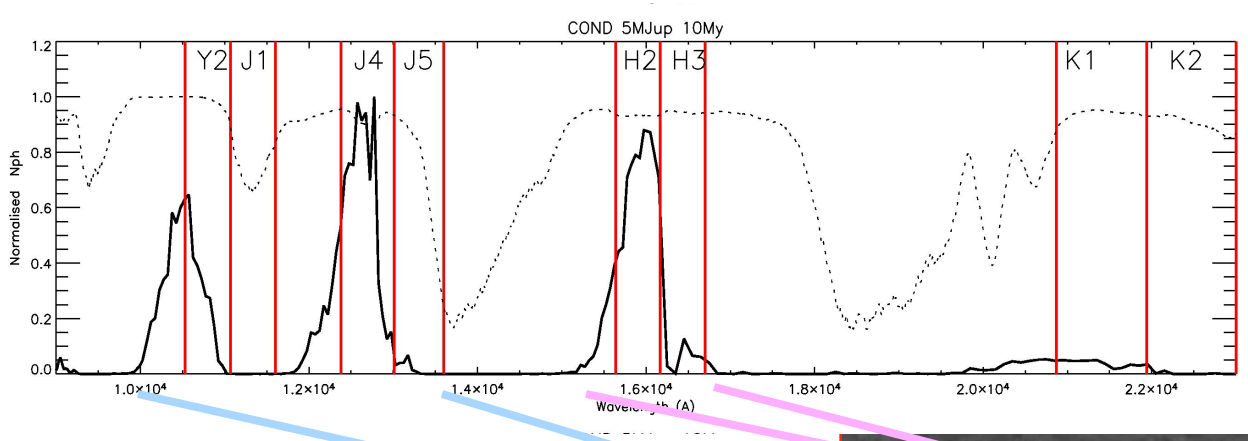


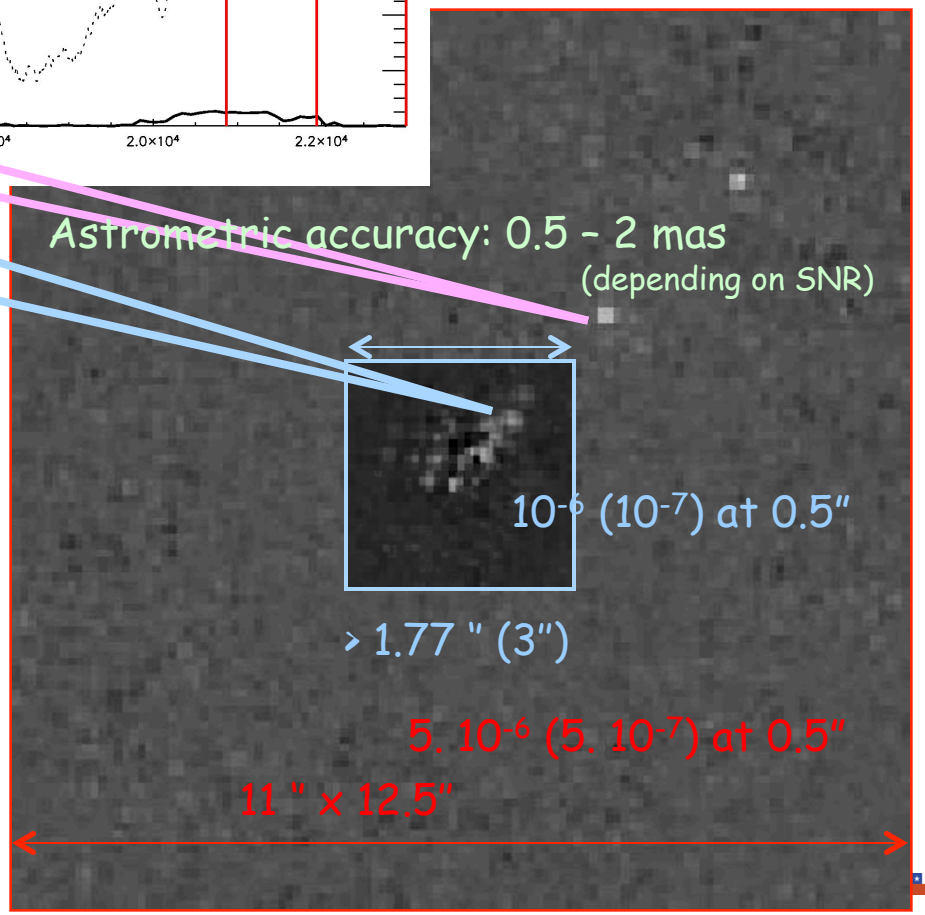
10^{-7} – 10^{-6} expected contrast level



Talbot effect included in the model (Mesa et al. 2011)

Differential imaging IFS/IRDIS



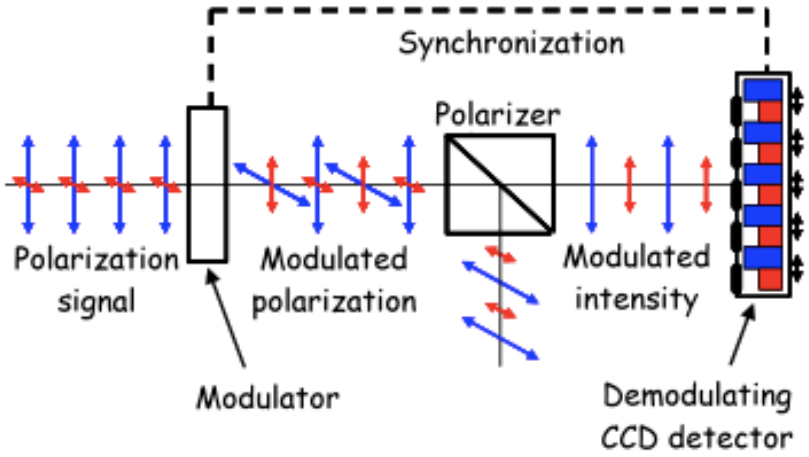


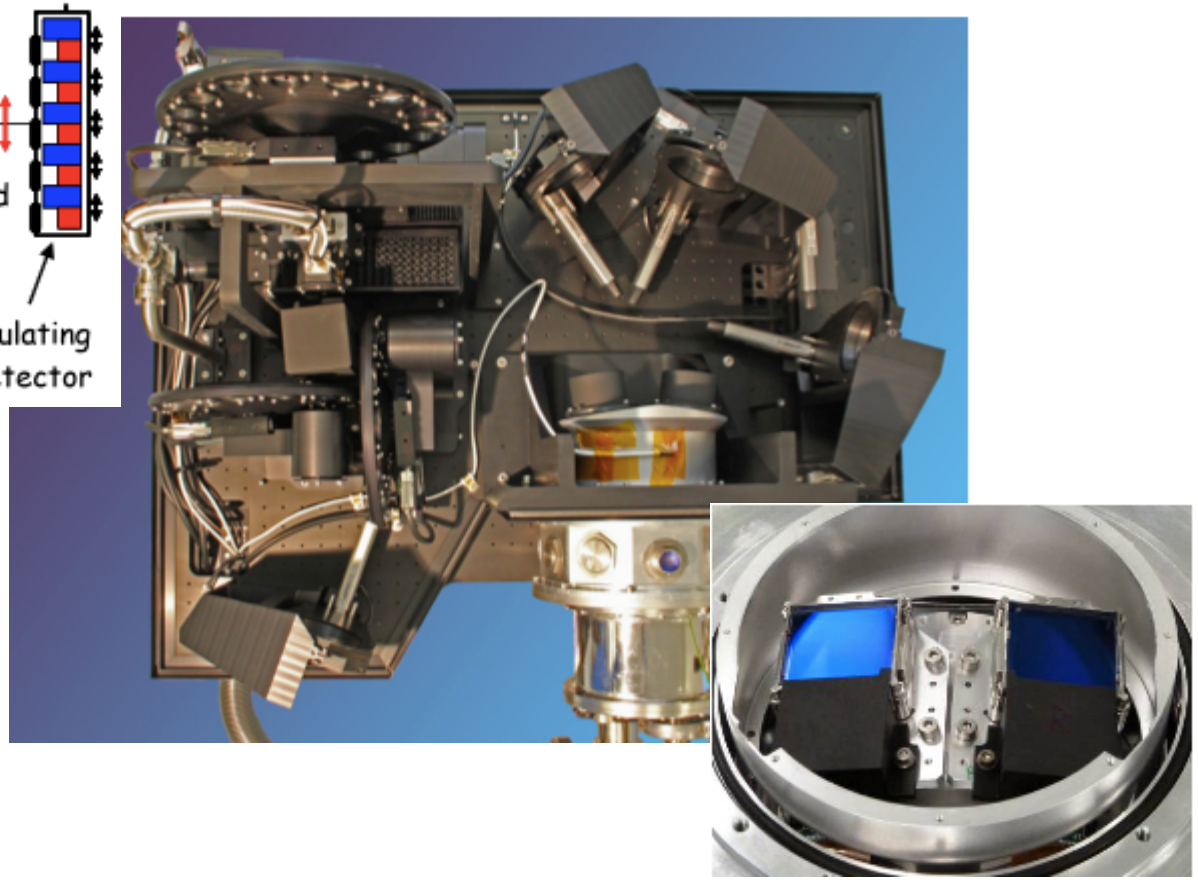
Simultaneous use of
Y-J band with IFS
Dual imaging in H

- Multiplex advantage for field and spectral range
- Mutual support: false alarm reduction, operation, calibration
- Immediate companion early classification

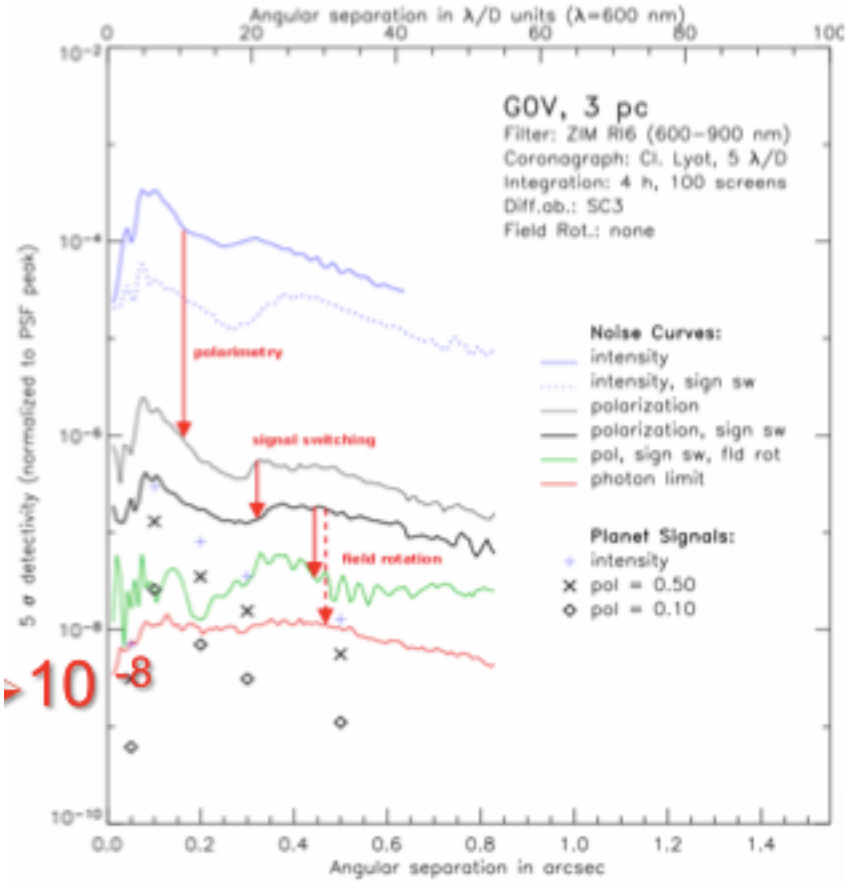
ZIMPOL

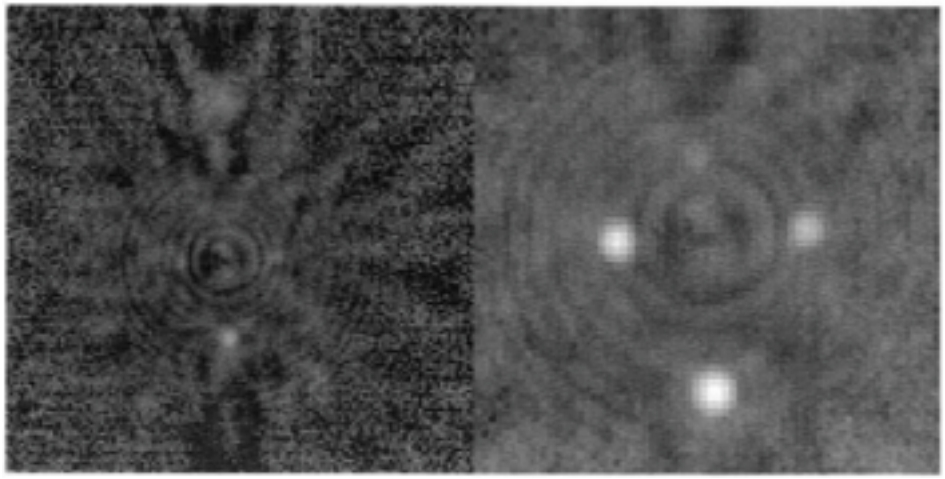
- Visible differential polarimeter





Expected Perf





Planet	Angular Sep (mas)	Int. Contrast
Top	70	2e-7
Left	80	7e-7
Bottom	150	9e-7
Right	100	3e-7

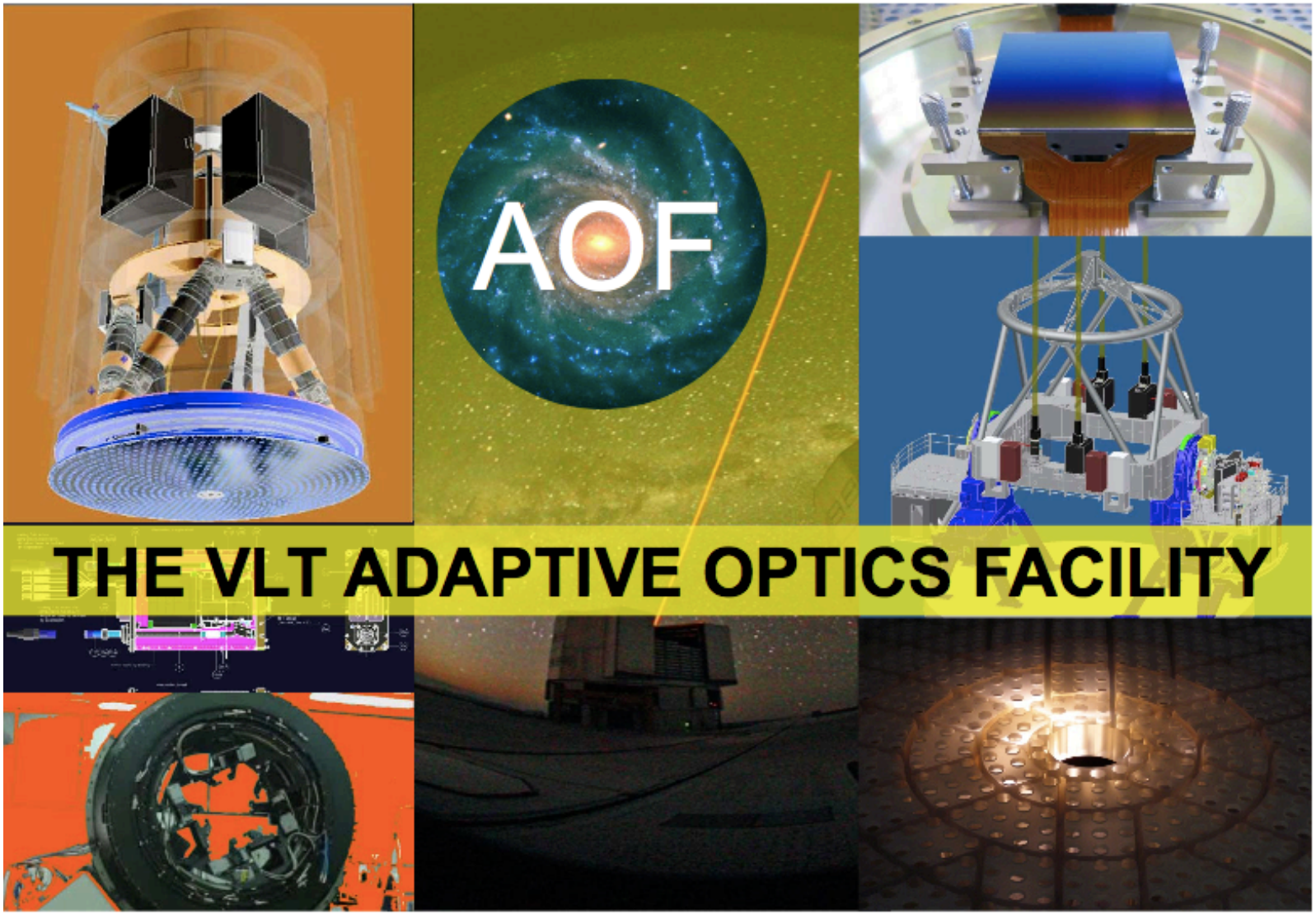
Current status and preliminary schedule

- IRDIS, IFS, ZIMPOL, CPI: year-long sub-system level quality and operation checks, problem solving characterizations - 2011

- System integration in Grenoble
  - IRDIS and IFS integrated on CPI – Dec 2011
  - ZIMPOL integrated on CPI – Jan 2012
  - SAXO acceptance – Mar 2012
  - System level image quality: closing the loops, stability checks, … - March-April 2012
  - Full system operation and performance in all modes – Summer 2012

- PAE – end of Summer 2012
- Shipment, reintegration, first light: end 2012
- On-sky critical tests for observation validation: Feb 2013
- First CfP: March 2013

Glimpse of the Future



In 10 years from now